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7/25/68

EFFECT OF LOAD ANGLE ON THE COMPRESSIVE FAILURE OF FIBERGLASS/EPOXY FACED, HONEYCOMB SANDWICH STRUCTURE

A THESIS

Presented to

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by

Robert Butler Lantz

In Partial Fulfillment

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Master of Science in the

School of Engineering Mechanics

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September, 1968

EFFECT OF LOAD ANGLE ON THE COMPRESSIVE FAILURE OF

FIBERGLASS/EPOXY FACED, HONEYCOMB SANDWICH STRUCTURE

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Date approved by Chairman: Sept 6, 1968

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

SUMMARY

An investigation of the response of orthotropic, fiberglass-faced, honeycomb core, sandwich structure compressively loaded at various angles to the material axes was conducted on typical short column, lightweight, aircraft type, edgewise compression test specimens. The mechanical properties of the fiberglass reinforced plastic laminate face sheet material were obtained using laminate test methods. The integrity of the fabricated sandwich panels was assured by sandwich quality control tests performed on samples of each fabricated panel.

Edgewise compression tests were performed at 0°, 30°, 45°, 60°, and 90° to the major material axis of the test specimens. Some of the specimens were instrumented with strain gage rosettes, some with photoelastic coating, and some were uninstrumented. These tests provided measurements of ultimate strength, observations of failure modes and, in selected cases, face sheet elastic properties. The experimental results were then compared with predictions of failure modes and strengths derived from relationships available in the literature. The laminate compressive strengths and moduli and the sandwich face sheet compressive strengths and moduli were also compared.

The results of the investigation indicate that the edgewise compression test provides an excellent means to test off angle, thin gage fiberglass-reinforced plastic laminates for strength values. The shear crimping and face wrinkling predictions proved inaccurate.

CHAPTER I

INTRODUCTION

Orthotropic/Orthotropic Sandwich

The early promise of light weight structural sandwich composed of fiberglass reinforced plastic face sheets on light weight cellular honeycomb core has never been realized due to a lack of available commercial material and recognized analysis methods. Early proponents of sandwich structure were, and continue to be, the aircraft companies where the conceptual advantage of an apparent gain in bending stiffness with little resultant weight penalty has always appeared attractive. Early in their work, they investigated the performance of layered sandwich structures composed of isotropic face sheets (such as aluminum) and isotropic core (such as balsa wood or foam). Later, improving the core by changing to a cellular orthotropic honeycomb resulted in a more efficient structure but complicated any analysis. Again increasing the efficiency of the structure by utilizing orthotropic face sheet material, such as fiberglass reinforced plastic (FRP), further complicated the analysis.

Although a great amount of effort has been expended to analyse the simplest form of sandwich structure, isotropic face sheets on isotropic core [1, 2, 3, 4]* and a smaller, yet significant effort has been recorded for analysing the more difficult construction of isotropic face

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*Numbers in brackets indicate reference numbers sheets on cellular honeycomb (orthotropic) core [3, 5, 6, 7, 8, 9, 10, 11], little recorded information is available for orthotropic face sheets on orthotropic core [12, 13, 14, 15, 16, 17].

Adhesive Prepregs

Recent material advances by FRP manufacturers have renewed interest in orthotropic/orthotropic sandwich structure by providing new materials which offer too many advantages in fabrication, structural integrity and cost effectiveness to be disregarded. The new materials, called adhesive prepregs, do not require an adhesive to bond the face sheets to the core. The uncured resin impregnated FRP face sheet material is positioned directly on the core and placed under approximately 25 psi pressure at about 250°F for nearly two hours in order to effect a cure. During this cure cycle, the special formulation epoxy resin, which is the face sheet impregnant, "flows" and "fillets" directly around the ends of all the honeycomb cells against the face sheet material in exactly the same manner as an epoxy adhesive would perform and, in fact, forms an epoxy bond between the face sheet and core in a "one-step" cure as just described. Many advantages of such systems immediately come to mind.

(1) Adhesive costs are eliminated.

(2) Bonding of the layers of the face sheet material has been accomplished using a tougher epoxy adhesive than the normal epoxy laminating resins.

(3) Weight is reduced through elimination of adhesive.

(4) No adhesive/laminating resin compatibility problems are present.

(5) No cure temperature differentials exist (the sandwich is processed at only one temperature, 250°F, a low cure temperature at that).

(6) Processing techniques for curved parts are simplified.

(7) FRP epoxy materials are well known for their resistance to environmental and handling damage.

It is understandable then why the airframe companies have demonstrated a renewed interest in such sandwich structure.

However, the utilization of such FRP faced sandwich structure is accomplished presently through the use of empirical data generated solely for the particular configuration under consideration (as in Reference 17). Typically, such airframe structures are constructed of two or three ply face sheets of 181 or 120 style fabrics bonded on cores with densities of three to eight pounds per cubic foot and cell sizes of 1/8, 3/16 or 1/4 inch.

Failure Modes

Since the sandwich structure, by virtue of its design, is resistant to bending, the critical aircraft design conditions often become the compressive instability characteristics of the various panel constructions. Depending on the overall panel configuration and constituent configurations, sandwich structure, whether composed of isotropic or orthotropic core with either isotropic or orthotropic face sheets, under edgewise compressive loading will fail in one or a combination of the following modes:

(1) General instability (overall Euler buckling)

(2) Face sheet compression strength

(3) Face sheet wrinkling

(4) Shear crimping

If the core is a cellular type, like orthotropic honeycomb, a fifth failure mode possibility exists:

(5) Face sheet dimpling (intracellular buckling)

Figure 1 demonstrates these failures.

Analysis Methods

Generally, the existing analysis methods in theoretical or empirical form exist as separate criteria for the different modes of failure. This is especially true for sandwich constructed of orthotropic core and orthotropic face sheets.

The primary theoretical analysis concerning orthotropic/orthotropic sandwich structure appears in the report by Ericksen and March [12] where they concern themselves with the general instability mode of failure and the various boundary conditions. Later reports by Kuenzi [10] and Plantema [3] all refer back to this work. Two other reports are significant when considering the face wrinkling mode of failure. The report by Norris, Boller and Voss [9] and the one by Yusuff [6] each present an empirical approach to the face wrinkling buckling of a sandwich panel constructed of cellular honeycomb core, with isotropic face sheets. Nordby and Crissman [14] used these criteria for orthotropic fiberglass face sheets on honeycomb core; correlated some 0° and 90° load angle tests; found discrepancies; but considered them reasonable and reported that for these constructions the theories should be used with care; and noted that such were the only theories available.

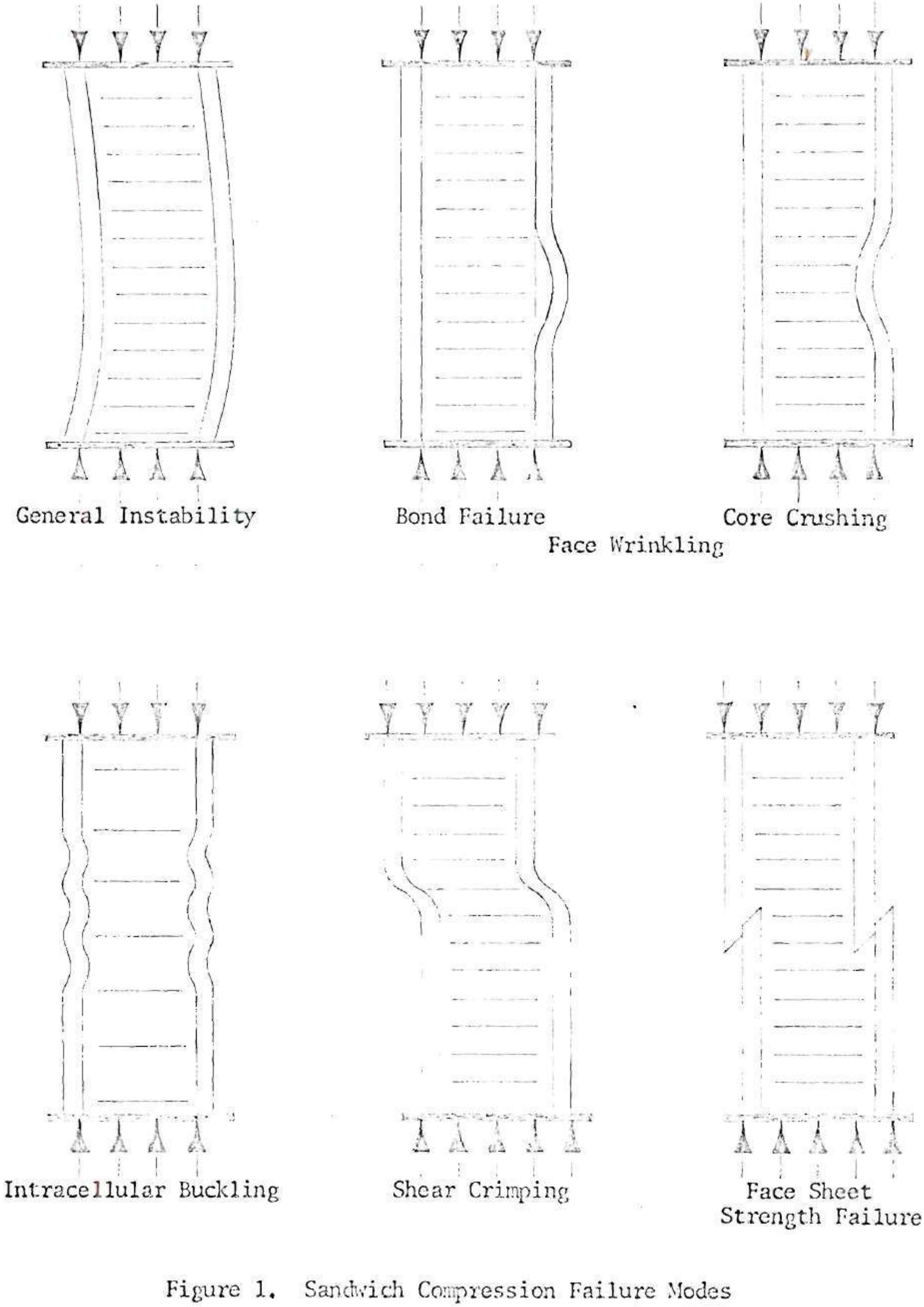


Figure 1. Sandwich Compression Failure Modes

According to Norris, Boller and Voss, shear crimping is a consideration only when the face wrinkling stress can exceed a core shear stress cut-off which is a function of the core shear modulus. Nordby and Crissman concur and state that for sandwich of thicknesses suitable for aircraft structures, this failure mode causes no problems.

Nordby and Crissman also declare that for cell sizes of under one-half inch, intracellular buckling will also cause no problems. They base their comments on their work [14] and that of Norris [18].

Almost all the empirical and theoretical developments on orthotropic/orthotropic sandwich have been applicable to the type layup first specified in Reference 12 by Ericksen and March. They specified that the two orthotropic axes of the core and facings were to be parallel to the edges of the panel with a third axis perpendicular to the facings. Such a construction is a common result of efforts to simplify the many possible combinations of axes directions. The warp direction (a natural axis) of each FRP lamina of each face sheet is laminated in the ribbon direction (a natural axis) of the honeycomb core. Such a structure has a major natural axis, the ribbon/warp direction, and a natural axis at 90° to the major axis. Another core axis, the longitudinal cell direction, is perpendicular to the face sheets.

Empirical Pitfalls

The standard edgewise compression test specimen as specified in ASTM Standard Test Method C 364-61 [19] is a short column, loaded in the ribbon direction of the core and designed so that the face sheets fail in compression. The data obtained from these tests are used by designers as the compression allowable for face sheet material under any planar load. When the face sheets are made of isotropic material (or nearly isotropic), such as aluminum, these data will probably be valid for load input at any planar angle to the face sheet because any angle of load off the ribbon axis of the core will influence the failure mode only as the elastic properties of the core change in that direction from the ribbon direction. These properties won't change sufficiently to influence the failure mode and a face sheet compression strength failure will probably occur at much the same load on the isotropic face sheet material, regardless of direction.

If the specimen was so designed that the face sheets were able to withstand the compression loads to the point of incipient buckling, the core would then act as an elastic foundation and would influence the instability failure mode. Any edgewise compression specimen for isotropic face sheets will therefore fail in face sheet compression strength, face wrinkling, or shear crimping depending on the properties of the constituent materials, regardless of load angle input.

Such is not the case for orthotropic and, in particular, fiberglass faces. The modulus and strength values change considerably as the planar load angle to the warp direction changes. This means that although the face sheet material will fail in compression at a 0° load angle (the ribbon/warp direction) and probably at a 90° load angle (since the respective strengths and moduli are numerically close at these angles), at other angles, the modulus values drop so low that a low value for face sheet wrinkling strength could become the determining failure criteria; yet the designers use the 0° and 90° load angle data, as this is the only information available, even for loads at other angles.

Purpose of Research, Scope

The objective of this investigation is to contribute to the understanding of orthotropic, fiberglass faced, honeycomb core, sandwich structure through an examination of the response of such structure at various load angles to the material axes of typical short column, light weight, aircraft type, edgewise compression test specimens composed of three ply, 181 (75DE181) style fabric face sheets on three common size cores (1/8, 3/16 and 1/4 inch cell).

An orderly plan of study directed towards this objective was accomplished by following a sequential set of steps as follows:

(i) Establish experimentally the mechanical properties of the non-isotropic fiberglass faces of the sandwich. This was accomplished through a sequence of tension, compression and flexure tests at various load angles with respect to the principal direction of the composite/laminate.

(ii) Run a series of tests to establish sandwich quality control criteria in flatwise tension, flatwise compression and short beam flexure. These tests also provided information necessary to ascertain if the panels possessed certain minimum properties for face wrinkling type failure.

(iii) Perform a photoelastic evaluation of selected typical edgewise compression specimens to assure continuity of bond between face sheet and core and uniformity of load introduction.

(iv) Perform a number of tests in edgewise compression at 0°, 30°, 45°, 60°, and 90° to the principal direction of the sandwich on several sizes and weights of honeycomb core in order to determine experimentally the nature of failure as well as load. These tests provided measurements of ultimate strength, determination of failure mode, and, in selected cases, face sheet elastic properties (through strain gaging techniques).

(v) Compare the experimentally deduced results of the laminate and sandwich tests with theoretical predictions and semi-empirical relationships available in the literature.

Tests Performed

The following tests were performed to provide data for comparative analysis, or quality control purposes:

Laminate Tests

Tension at 0°, 90° and 45°
Compression at 0°, 30°, 45°, 60° and 90°
Flexure at 0°

These tests were performed on 12 ply laminates constructed of the same material as the face sheets of the sandwich structure. Strength and modulus were determined. Additional tests or calculations of a quality control nature were performed:

Resin content
Specific gravity
Void volume of laminate

Sandwich Quality Control Tests

Flatwise tension
Flatwise compression
Flexural shear

These tests were performed on selected samples for each core size.

Sandwich Photoelastic Edgewise Compression Tests

These tests were performed on samples of each core size for 0° and 45° orientation. The samples were picked to represent the two strain response extremes of typical edgewise compression samples.

Sandwich Edgewise Compression Tests

Two types of tests were performed:

Instrumented. 3/16 core specimens at 0°, 30°, 45°, 60°, and 90°, instrumented by strain gages to provide elastic properties of face sheets, along with failure mode and ultimate strength.

Uninstrumented. 1/8 core, 3/16 core, and 1/4 core specimens at 0°, 30°, 45°, 60°, and 90°, to provide failure mode and ultimate strength.

A set of uninstrumented tests of all core sizes were performed initially to determine the cell size specimens to be instrumented.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

Instron Description

All mechanical tests were performed on an Instron Universal Testing Instrument, Model TT-D-L. This machine incorporates a highly sensitive, electronic weighing system with load cells that use strain gages for detecting and recording tensile or compressive load. The moving crosshead is operated by two vertical, low speed drive screws. A positional servomechanism maintains accuracy and alignment control over the crosshead motion. The chart of the recorder is driven synchronously at chosen speed ratios (with respect to the crosshead), enabling measurements of sample deformation to be made with varying magnifications. The machine is also equipped with a servo system and strain gage preamplifier which alternatively allows the chart to be driven directly by a measuring extensometer attached to the test sample.

Two load cells were used interchangeably, depending on the expected ultimate load. One cell, used for low load indication, has a maximum full scale sensitivity of 0-1,000 pounds; the other cell, used most often, a maximum full scale sensitivity of 0-20,000 pounds. These cells are tension-compression cells and can record load under either type (tension or compression) loading, depending on the test set-up and location of the cell.

The load cells incorporate bonded strain gages mounted within the cell housing on a strain sensitive simple tension member. The internal member is supported by means of diaphragms, eliminating response to non-axial loading. Positive stops within the housing and shear pins in the specimen grips protect the internal member from accidental overloading and the resultant (possibly unknown) damage to the gages. The strain gages in the load cell operate similarly to the strain gages used for test investigations. An applied load on the cell causes a proportional change in the resistance of the strain gages mounted on the calibrated internal tension member. The gages are arranged in a Wheatstone-bridge circuit and excited by a stabilized oscillator. The resulting signal is amplified, rectified to d.c., and fed to the pen driving circuit of a high speed potentiometer recorder. Within the amplifier circuit are means to compensate for the weights of the jaws, fixtures and the samples themselves. The sensitivity of the amplifier may be changed in calibrated steps of full range ratios of 1, 2, 5, 10, 20, 50, 100, and 200, depending upon the particular load cell. The accuracy of the load weighing system is ±0.5% of the load or ±0.25% of the recorder scale in use, whichever is greater.

The crosshead operates on a constant strain rate, or "hard" principle, and loads a specimen through vertical drive screws which produce a constant straining of the specimen regardless of load response. The crosshead speed can be varied at any time during test by means of fast response electro-magnet clutches operated by pushbuttons which provide seven standard speeds. This feature was utilized during extreme strain deformation to speed up the duration of the test after initial strain values were determined.

The recording system incorporates a potentiometer driven pen arm, described earlier as the output medium for the load weighing system, and a means to drive the chart on an orthogonal axis to the load axis. Two means are used to drive the chart.

The first is a synchronous motor with various change gears used to drive the chart at a constant speed at ratios of up to 250:1 of the lowest available speed. Because of their synchronous operation, there is a correspondence between the individual motions of the chart and crosshead. This close relationship is maintained by virtue of the low inherent deflection of the load cells and by the almost total elimination of backlash in the crosshead drive assembly. However, since the chart is not coupled directly to the crosshead, the chart drive direction can also be considered a time axis.

For reduced area test specimens, specimens of extreme low total deformation, or other special configurational specimens, direct strain measurements on the specimen can be accomplished by using the second means of driving the chart, which is termed the X-Y Chart Drive System. This system incorporates a high performance servo system consisting of an amplifier, control circuits, and a chart drive assembly which drives the chart in response to an input signal for the extensometer, deflectometer, or strain gage. Although not performed here, the chart can be driven directly from a bonded strain gage on a specimen.

Change gears allow magnification of chart response up to a total field of 10 inches of chart travel. Parallel clutches provide the capability to switch back and forth between the two described methods of chart drive.

Strain Measurements

Extensometers and strain gages were used to obtain strain measurements directly from the test area of the specimen. For the fiberglass laminates, an extensometer was used to measure tensile and compressive deformations. For the selected sandwich edgewise compression specimens, strain gages were used.

The extensometer used was the Instron G-51-11, one-inch gage length, 10% maximum strain extensometer. The extensometer signal was fed into the X-Y chart drive recorder yielding an available magnification range of up to 1000/1. The extensometer incorporates a light weight housing for an internal strain gage circuit. Extending from the housing are two light weight rigid arms that clip on the test specimen. The internal strain gages are bonded on a flexure element connecting the two extending arms. Bending of the element with specimen elongation strains the gages, changing their resistance to provide the signal driving the X-Y chart. The extensometer incorporates a positive stop and space bar that provides a means to establish the initial gage length and prevents the extensometer from damage from over-extension. The extensometer is positioned on the test specimen using the knife edges on the ends of the extensometer arms and a straddle clip that applies a spring-loaded plunger on the opposite side of the specimen with enough force to support the extensometer and insure proper seating of the knife edges. The entire assembly weighs 42 grams and is light enough to negate any inertial effect of the arms or the extensometer body.

Strain measurements on the sandwich edgewise compression face sheets were obtained using strain gages bonded directly to the face sheets. The gages were BLH FAR-25-12-45 S-13, three-arm (45°), epoxy-backed, foil rosettes. The gages were aligned to 0°, 45°, 90° to the test axis; one on each face sheet on the center line. The gages were bonded, using Eastman 910 acrylic adhesive, after cleaning the surface with methyl ethyl keytone (MEK). The gages were connected to a BLH Type 225, 10 channel Switching and Balance Unit which was then connected to a BLH Model 120C Strain Indicator Unit. Each arm was connected to a separate channel on the switching and balance unit and each channel was zeroed to a convenient setting using the built-in balancing potentiometers. The channel selector switch then allowed each signal to be individually monitored by the Strain Indicator Unit.

The Strain Indicator uses a manually operated null-balance system with a digital readout. The Indicator measures the change in electrical resistance of the strain gage connected to the channel being monitored. Through the null-balance system, using the input constants such as resistance and "gage factor" of the strain gage, the Indicator transforms the signal change into the displayed digital reading in micro inches per inch strain.

Photoelastic (Photostress) Equipment

Although the photostress technique can be applied to many problem areas when investigating composites, the technique was used in this study to examine the load introduction response of the sandwich edgewise compression test specimen.

Selected specimens were coated on the faces with the birefringent material and then examined, using polarized light during the axial edgewise compression test. The selected specimens were coated on both sides (to balance the specimen) with Photolastic, Inc. PS-2, 0.046-inch thick, high sensitivity, low elongation photostress sheeting, using the compatible PC-1 cement with PCH-1, 10 phw hardener. Handling of the sheeting poses some problems because the material is brittle and heat sensitive. Therefore, machining of the sheeting cannot be accomplished too fast or chipping will occur, or too slow or distortion will occur. The sheeting was cut almost to size on a Syncro Jig Saw, Model 1004, Syncro Corporation, Oxford, Michigan, a small model-making type tabletop jig saw. The edges were finished, net, by sanding over 280 grit Silicon Carbide sandpaper, using clean paper each pass. The ends of the sheeting were beveled back near the tangs of the specimens to later allow adhesive to cover the ends of the sheeting to prevent end-peeling during test.

The specimen surfaces were prepared for bonding by lightly abrading the surface with the same sandpaper, applying a Photolastic, Inc. proprietary "metal cleaner" using disposable gauze pads, applying a proprietary "Neutra-Sol" and finally cleaning with alcohol. The ends of the specimens were masked and the surface not being bonded was protected, using masking tape. The adhesive, which has a pot life of about twenty minutes, was brushed on as a thick coat to insure wetting. The prepared sheeting (prepared to size) was then applied in a manner allowing the sheeting to spring down from one end to the other, forcing the adhesive to flow ahead of the contact of the sheeting and the specimen thereby removing any entrapped air. The adhesive was then spread on the edges of the sheeting and specimen and built up at the beveled ends. After the adhesive had set (about twenty minutes), the excess adhesive was removed and the top of the sheeting was cleaned with acetone and then alcohol. The masking tape was removed from the specimen end area and care was taken to make sure a separation existed between the clamp area and the adhesive to guard against a load path leading to the coating which could load the coating directly and bias test results. After an hour, the specimens were able to be turned over and the coating was applied to the other side using the same procedure. Cure time for both adhesive systems was a minimum of twelve hours.

A Photolastic, Inc., Model 031 basic analyzer reflective polariscope was used to observe the strain pattern of the selected specimens. A 35 mm camera was used to record the patterns. The instrument was zeroed while the specimen was under no load and the analyzer set to determine the magnitude of principal strain differences. This was accomplished by inserting quarter-wave plates into the viewing field which removed the isoclinic lines (lines of constant principal strain direction) and allowed comparisons of magnitude of principal strain difference values at different points on the instrumented surface which amounted to viewing changes in the strain field due to the influence of the load introduction. No discrete strain readings were obtained, so no additional accessories were required.

Special Test Fixtures

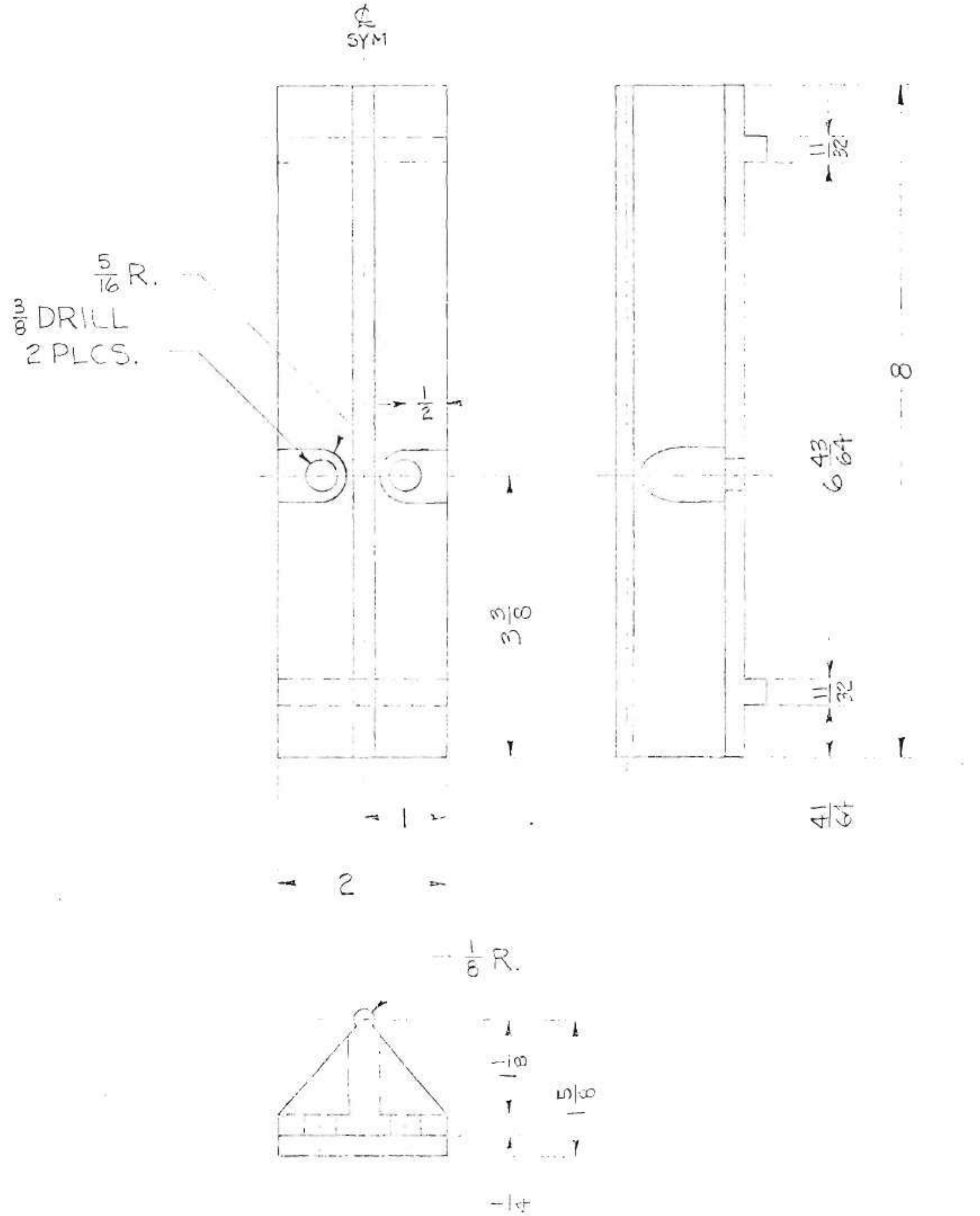
Special test fixtures were designed, fabricated, and installed on the Instron to perform some of the specialized sandwich and fiberglass laminate tests.

A special flexure tool was designed to load fiberglass laminates and sandwich panels in bending. A "three-point" or "four-point" loading can be accomplished using interchangeable upper and lower base plates and the required load rods. Each base plate can accommodate the load rods on a span from two inches to six inches. A single load rod can be placed in the center. The base plates can be positioned either axial to the crosshead or 90° to the crosshead axis. The loading rod has been fixed at one-eighth-inch radius. Loading rod adapters for sandwich testing include one-half-inch flat, three-fourths-inch flat and the ASTM recommended one-half-inch diameter rod.

Figure 2 shows the flexure base plates and the loading rods.

Tension testing was accomplished using the standard 20,000-pound Inston 10F Wedge Action Grips. The grip faces used were the special flat 25-teeth-per-inch diamond serration type, adjustable to open from zero to one-fourth inch. These grips are especially desirable for use with fiberglass reinforced plastics because of certain inherent design features. The grips are tightened onto a sample without altering the vertical position of the faces. This precludes any initial buckling of the specimen while loading in the grips. The grips operate on an ever-increasing wedging principle which allows the grips to maintain the force on the specimen even under high loads and specimen "drawing." After rupture, the grips exhibit no recoil, thereby maintaining the specimen and extensometer in the machine test area. The only drawback was that specimens greater than one inch could not be accommodated.

All compression tests and flexure tests were performed using a Tinius Olsen eight-inch-diameter 67-A-47 spherical seat which had a



Flexure Load Points

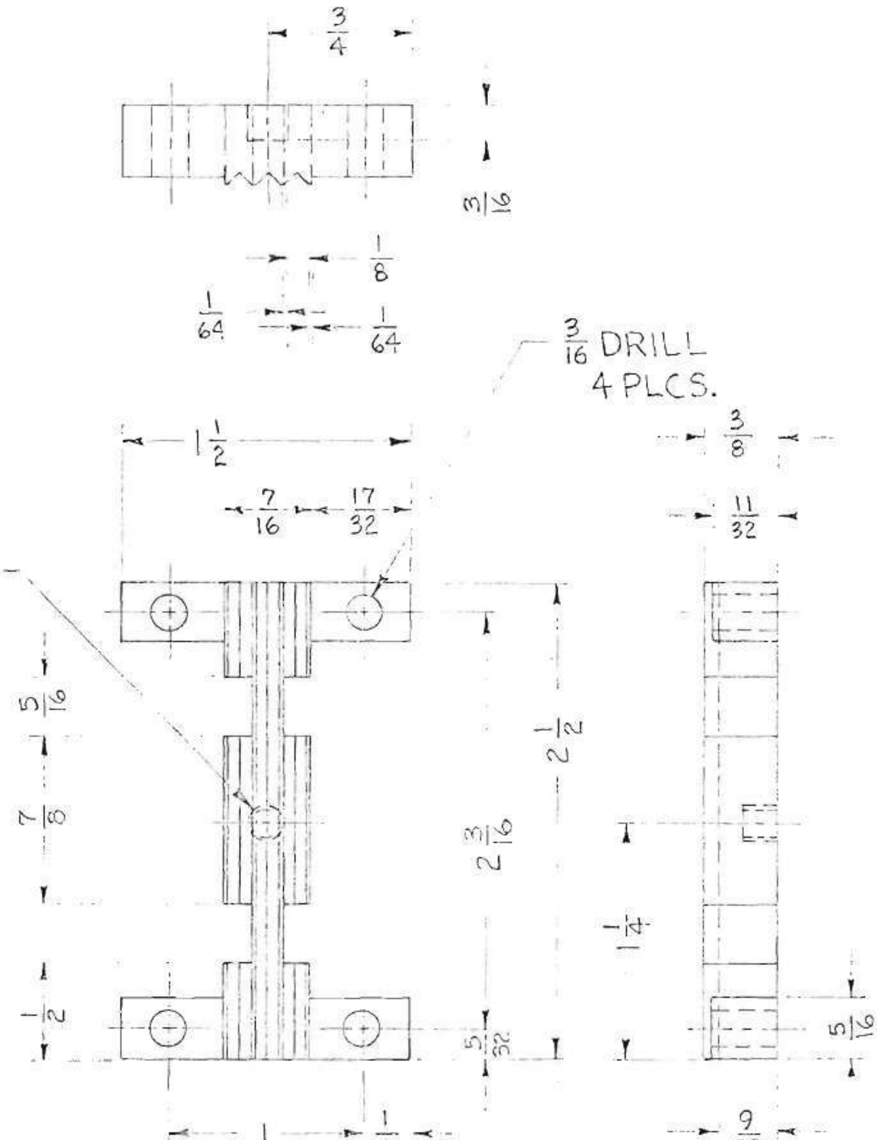
Figure 2. Flexural Test Fixture

recessed base to seat and center on the compression table.

Laminate compression specimens were tested using specially designed end clamps to insure flat and parallel loading to the specimen ends and a specially modified Federal Standard 406 type support fixture which was relieved to allow extensometer attachment. The sandwich edgewise compression specimens required no support fixture; however, scaled-up versions of the end clamps were used. Figure 3 shows the end clamps and support fixture.

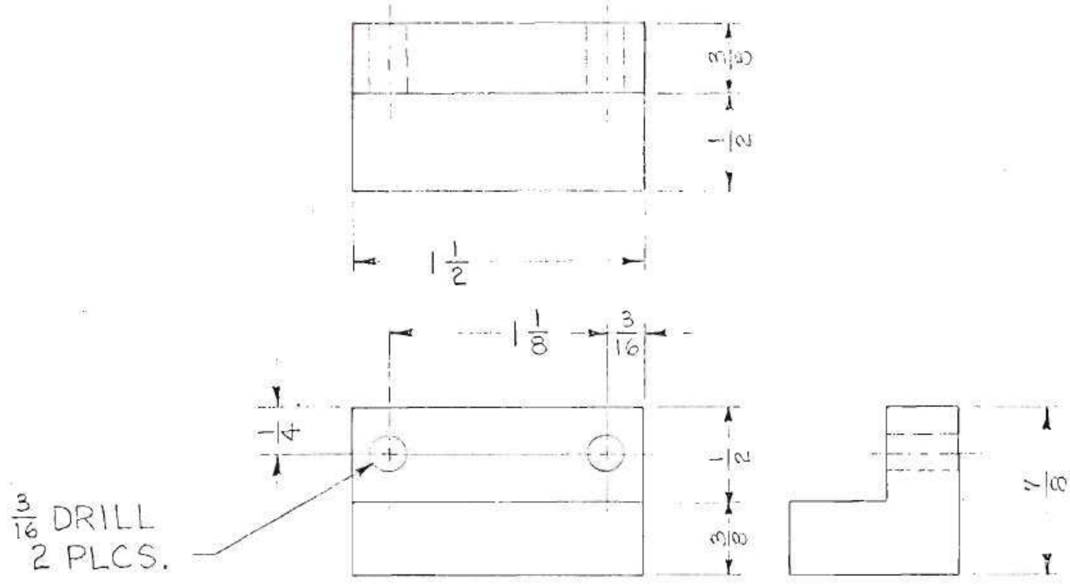
Flatwise tension tests of the sandwich specimens required the use of universal joints in the load train to preclude any off angle loading and the notching or tearing type failure. The universal joints were machined from J5 universal joint blanks purchased from the Boston Gear Company. Figure 4 shows the joints. Figure 5 shows a connector between the universal joint and the test specimen.

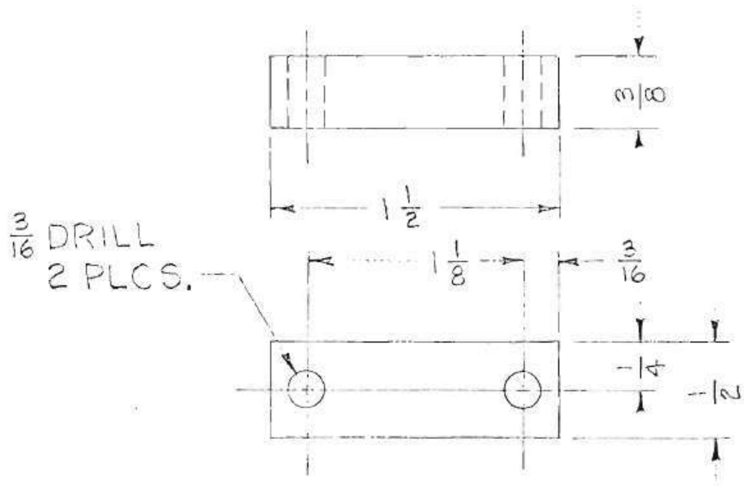
Attached directly to the connector were pinned loading blocks which had previously been bonded to the sandwich test specimen. The blocks were bonded using a low temperature curing epoxy adhesive, Magnobond 29A and B (Magnolia Plastics Company, Chamblee, Georgia), cured at 180°F for two hours. The surface of the blocks were faced on a lathe and etched using the FPL acid etch solution prior to bonding. The FPL etch solution consists of 22 to 25% sulphuric acid, 3 to 9-1/2% potassium dichromate merck, and the remainder clean H_2O, all measured by weight. The surfaces were rinsed in distilled water and air-dried prior to bonding.



Support Fixture

Figure 3, Laminate Compression Test Fixtures





End Clamps

Figure 3. Continued

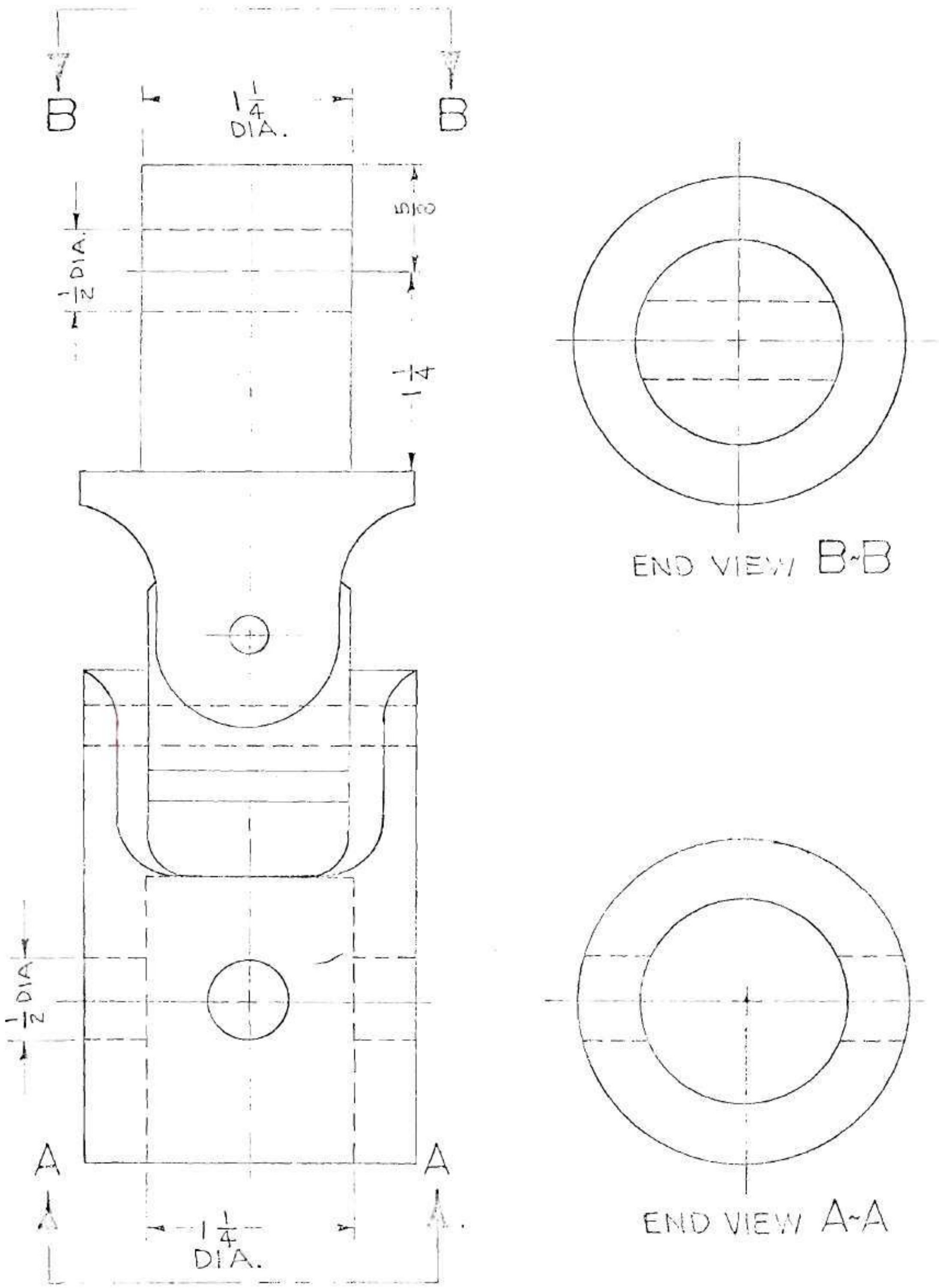


Figure 4. Load Train Universal Joint

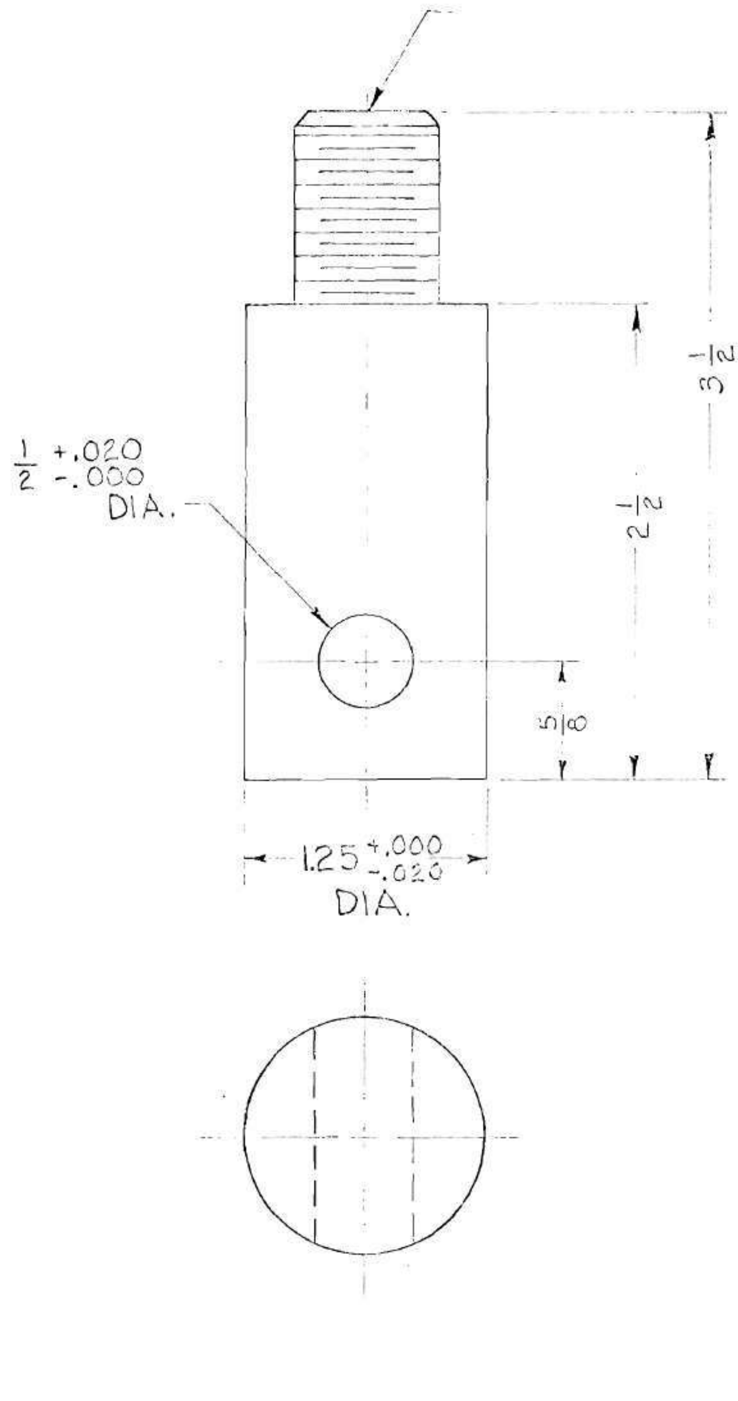


Figure 5. Flatwise Tension Adapter

Calibration

The Instron load cells are calibrated through the use of a calibration control incorporated in the amplifier controls. The calibration knob operates a ten-turn potentiometer which can vary the sensitivity of the amplifier continuously, thus adjusting the load cell scale sensitivity. This control is used after a known dead weight has been suspended within the load train. For the 20,000-pound capacity load cell, the amplifier incorporates a circuit which produces a signal corresponding to 500 pounds load. This load cell is normally calibrated using the internal electronic loading. This signal was checked against 100 pounds of actual dead weight and found accurate.

The Instron strain gage extensometers were calibrated using the Instron G-55-1 high magnification calibration fixture. The fixture consists of a large micrometer head mounted on a stand which enables the accurate manipulation of the extensometer over a relatively small distance.

The chart is normally calibrated over a range of ten inches of travel and the calibration fixture can be adjusted to 0.001" with a readable vernier of 0.0001".

The BLH Strain Indicator was calibrated by the local company representative using the BLH Model 625 Calibrator. The calibrator inputs known microvoltages to the strain indicator so the resulting strain reading can be checked. The calibration insures a tolerance of ±50 microinches per inch at ±20,000 microinches per inch.

Specimen Machining

Two special aids were used to machine the test specimens. These aids were cutting tools designed especially to handle the abrasive fiberglass reinforced plastics. One tool was a tungsten carbide band saw blade and the other was a table model, high-speed, precision contour milling machine.

The tungsten carbide band saw blade, manufactured by Remington Arms Company, has thousands of tungsten carbide particles permanently bonded to its entire cutting edge. Such a blade resists dulling and provides a long term cutting operation on the abrasive fiberglass reinforced plastic laminates and fiberglass faced sandwich structure. Using the blade on a conventional table band saw, no coolants or specimen feed controls are required even for one-eighth-inch-thick fiberglass laminates. A gulleted type saw blade was used. The band speed was 3,000 feet per minute. All blanks for tensile, compressive, and flexural laminate test coupons were rough cut using the saw blade. All sandwich specimens were cut to size with the blade.

Tensile, compressive and flexural laminate specimens were machined on all edges using the Tensilkut high-speed, precision contour milling machine manufactured by Sieburg Industries, Inc., Danbury, Connecticut.

The Tensilkut machine is the high-speed, precision contour milling machine which achieves machining by a series of light cuts with a carbide cutting tool, designed especially for fiberglass reinforced plastic laminates, rotating at 20,000 rpm. The depth of cut can be adjusted from 0.0005 inch to 0.250 inch by a precision micrometer control which spaces the template holding the roughed specimen from the cutting tool. The precision cutting depth, combined with the high rpm of the cutting tool, achieves a low chip load which reduces the cutting pressures to a minimum, achieving machined edges free of distortion or heat deformation.

The roughed test specimen is clamped in a precision master template which is manually moved across the Tensilkut table during the machining of the test specimen. The dimension and configuration of the test specimens are controlled by these templates with contour accuracies of ±0.0005 inch, as reported by the manufacturer.

For the compressive and flexural laminate specimens, straight sided templates were used to machine the straight sides. The compressive specimens were also machined in a special template that squared the ends flat, parallel to each other and perpendicular to the sides.

The tensile laminate specimens were machined using a template that contoured the sides of the specimen to a "dogbone" shape similar to that of ASTM D638-64T [20].

All non-machined edges of the laminates and all edges of all the sandwich specimens were hand-sanded to remove any frayed fibers and provide a finished edge.

CHAPTER III

EXPERIMENTAL PROCEDURE

The procedures used in testing and in the preparation for testing are reported in detail to facilitate thorough data analysis. The procedures are described in three sections: fiberglass reinforced plastic material property tests; sandwich quality control tests; and sandwich stability (edgewise compression) tests. The fiberglass reinforced plastic material property tests provided a data base needed to define the face sheet orthotropic properties. The sandwich quality control tests provided a data base to define the adhesive and core properties. All of these constituent properties are used to predict the response of the edgewise compression stability tests.

Fiberglass Reinforced Plastic Material Property Tests

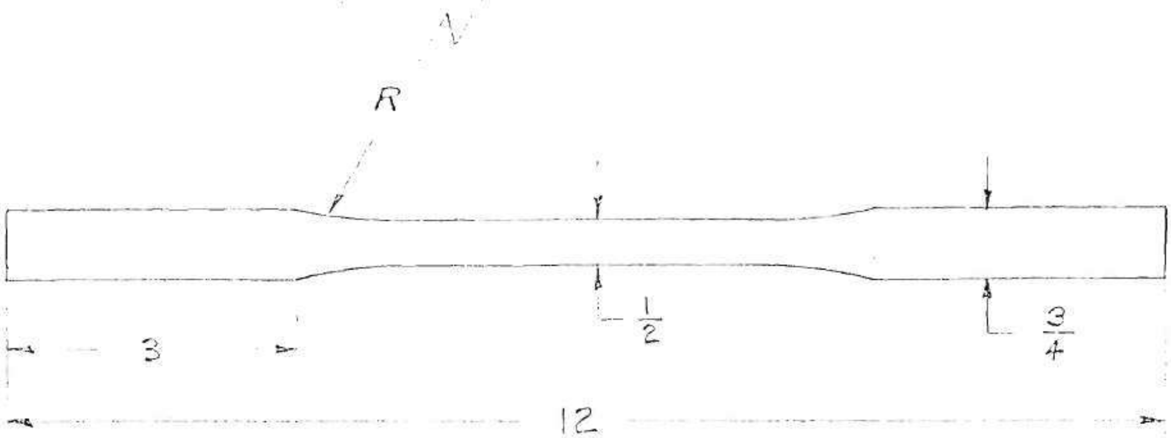
Three types of tests (tension, compression, and flexure) were performed on fiberglass reinforced plastic laminates fabricated to a standard laminate testing thickness from the sandwich facing material, BP919/75DE181. The number BP919 is assigned to the 250°F curing modified epoxy resin system developed as an adhesive prepreg material by the American Cyanamid Company, Bloomingdale Plastics Department. The panels were 12 plies thick, measuring approximately one-eighth of an inch. Specimens were trimmed from the panels according to the type test specimen and orientation, using the Remington bandsaw blade for rough cuts and the Tensilkut machine for all finishing work.

Laminate Tension

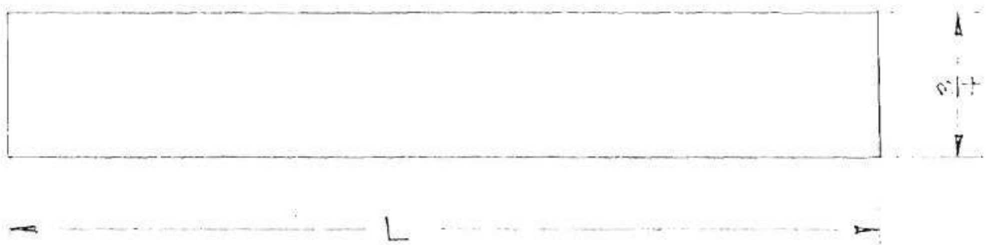
The tensile specimens were trimmed using a modified 50-43 Tensilkut template. The tensile specimen, shown in Figure 6, has been modified from ASTM D638-64T [20] in that the fillet radius, marked R on Figure 6, has been increased to 18 inches and the overall length subsequently lengthened to 12 inches to allow a tang length of three inches on each end. Such changes have insured that for all orientations of the fiberglass reinforced laminate test coupons, failures in the test section will occur rather than at the radius tangent point or in the tangs. All the tensile specimens were placed in the Instron wedge action grips which were attached to a load train incorporating a universal joint to insure alignment. General testing procedures conformed to ASTM D638-64T [20]. The Instron G-51-11, one-inch gage length, ten percent maximum strain extensometer was installed across the width of the specimen to measure elongation. Modulus values were obtained from the X-Y plot on the Instron recorder. The 0° and 90° load angle tensile specimens were tested at a crosshead speed of 0.05 inch/minute. The 45° load angle specimens were tested at 0.1 inch/minute. Figure 7 shows the laminate tensile test setup, including the extensometer location. Figure 8 presents a typical load-strain plot as received from the Instron recorder.

Laminate Compression

Laminate compression tests were performed following the general requirements of ASTM D695-63T [21]. Specimens were modified to provide a straight-sided configuration, and an extension in length to accommodate the end clamps. Figure 6 shows the compression specimen. The support jig was tightened finger tight using wing nuts at the four corners.



Laminate Tension Specimen



Laminate Compression Specimen

Figure 6. Laminate Test Specimens

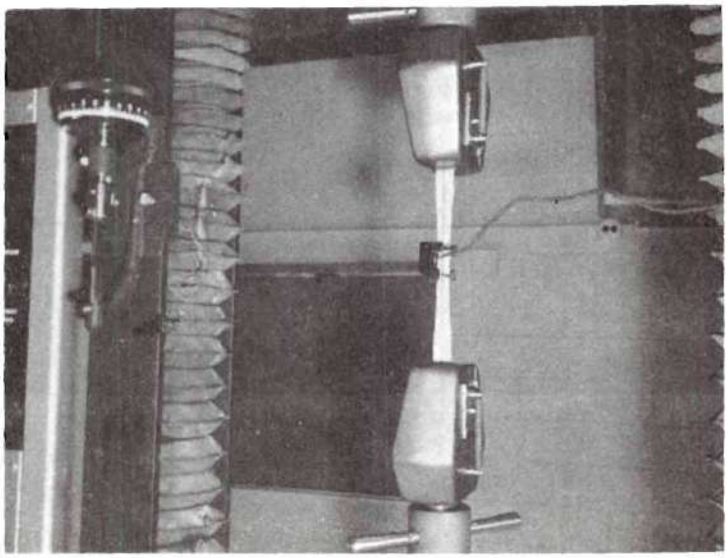


Figure 7. Laminate Tension Test

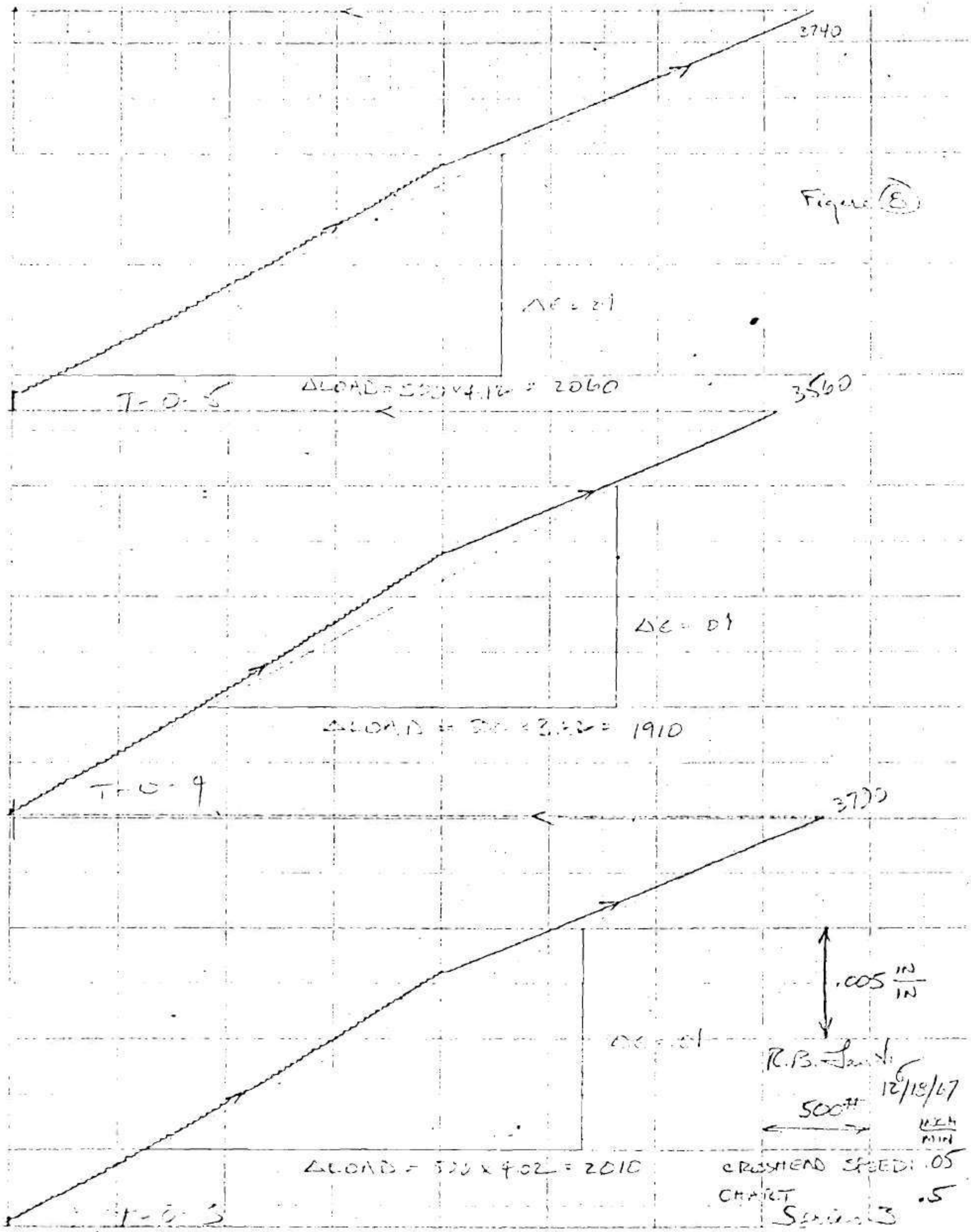


Figure 8. Instron Tension Load-Strain Plot

The end clamps were tightened, using an Allen wrench, to a snug position tighter than finger tight. The Instron G-55-11, one-inch gage length, ten percent maximum strain extensometer was installed across the thickness outside of the support fixture. The extensometer was opened and balanced in the open position and allowed to close the one-inch gage to record deformation. Using a set of calipers, the open gage length was measured and recorded for each specimen. The normal such gage length was about 1.05 inch. The measured gage length was used in calculating strain. The entire assembly of specimen, end clamps, support jig, and extensometer was placed on the top surface of a spherical seat. The crosshead was manually lowered to within approximately 0.05 inch of the top of the upper clamp surface and the spherical seat was visually aligned to insure axial alignment and loading. Tests at all load angles were performed at 0.05 inches per minute. Failures varied, but were generally the angled wedge compressive failure across the width near the center of the specimen. Figure 9 illustrates the test setup in the Instron. Figure 10 presents a typical load-strain curve recorded. Figure 11 shows a typical failure.

Laminate Flexure

Laminate flexure tests were performed as a quality control test (not as a material property test) and as such were standardized to follow ASTM D790-66 [22] exactly. Procedure A was followed, using a span-to-depth ratio of 16 to 1. This allowed a two-inch span for a one-inch-wide specimen, three inches long. Single point loading, using loading points of one-eighth-inch radius was accomplished at a crosshead speed of 0.05 inch/minute. Flexural modulus was obtained from the load

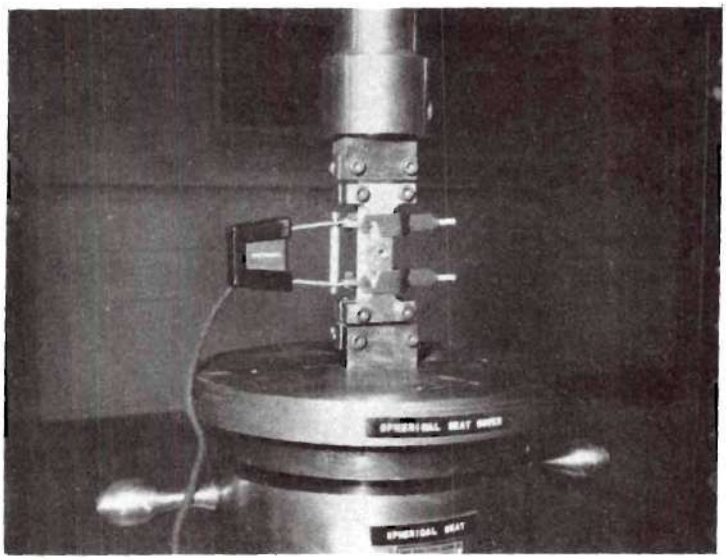


Figure 9. Laminate Compression Test

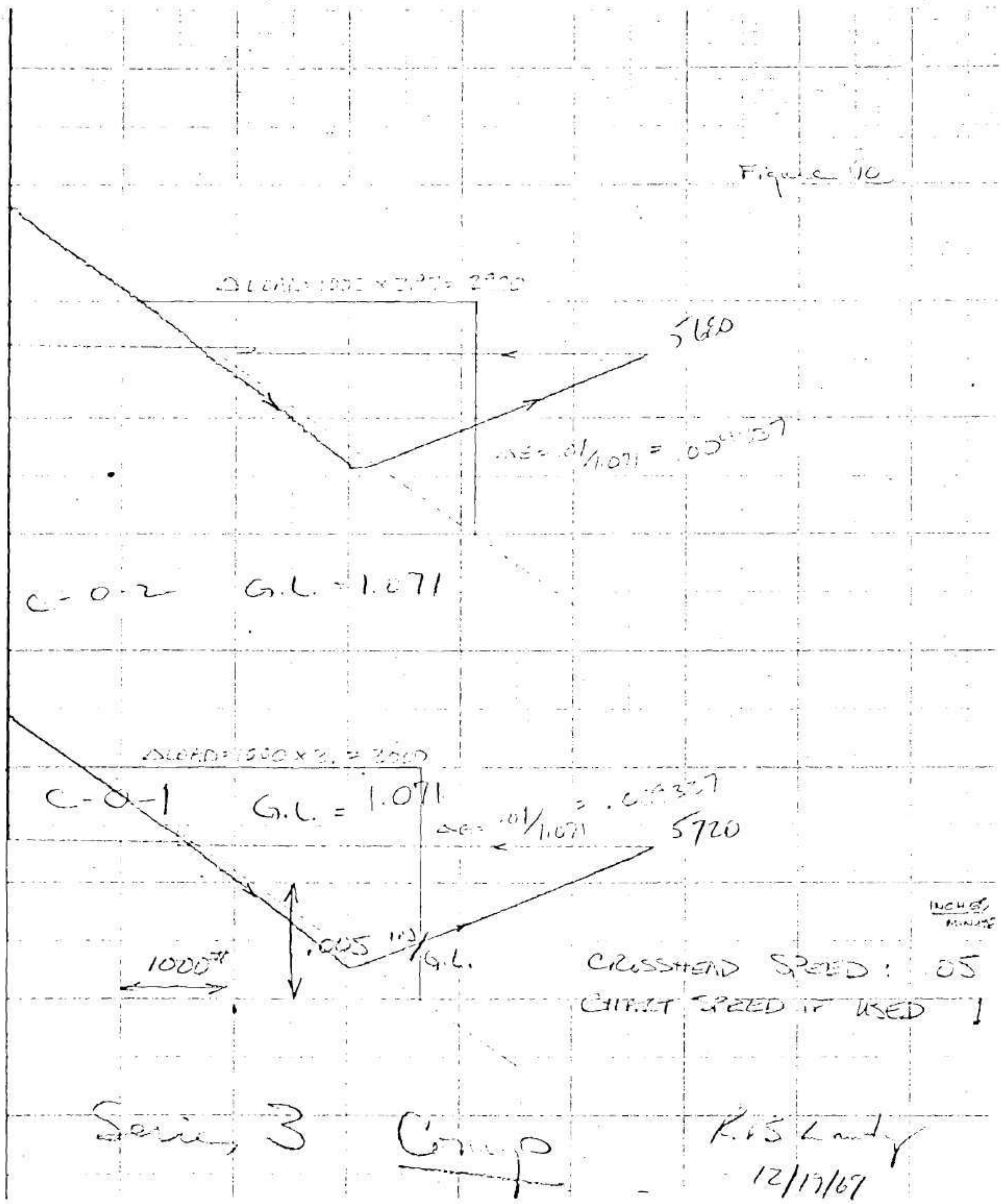


Figure 10. Instron Compression Load-Strain Plot

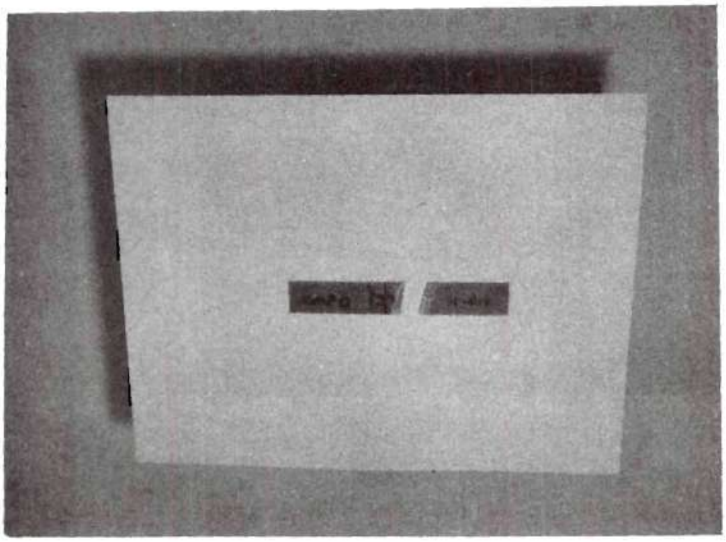


Figure 11. Laminate Compression Failure

deflection plot on the Instron recorder. Figure 12 shows the test setup.

Additional data were obtained to further define the laminate. Specific gravity of the laminates and percent resin content by weight were reported from the manufacturer of the panels. Using these data, along with the manufacturer's reported specific gravity of the epoxy resin system and the glass fabric, the percent void volumes were calculated using the methods of Reference 23.

Sandwich Quality Control Tests

Three types of sandwich tests (flatwise tension, flatwise compression, and flexural shear) were performed on certain panels to provide a base for later quality control tests and to develop certain constituent properties of the adhesive system and core.

Flatwise Tension

Samples from each type core (1/8", 3/16" and 1/4" cell size) were tested in flatwise tension generally following ASTM C297-61 [24]. Two-inch diameter round specimens were used rather than the one-inch square specimens described in the ASTM method. This was accomplished to eliminate influence of a corner toward a peeling failure. Loading blocks of the same diameter were bonded to the specimens using the FPL etch preparation and an epoxy adhesive. The specimens were measured prior to bonding for a mean diameter from which the area was calculated. The load blocks were inserted into the load train immediately below a universal joint. The crosshead speed was 0.02 inches per minute. Figure 13 shows a test specimen and one bonded to the load blocks. Figure 14 shows the test setup.

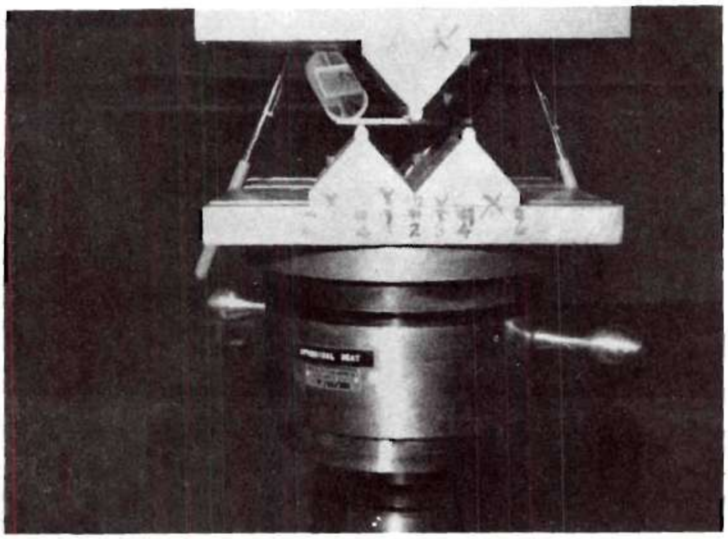


Figure 12. Laminate Flexure Test

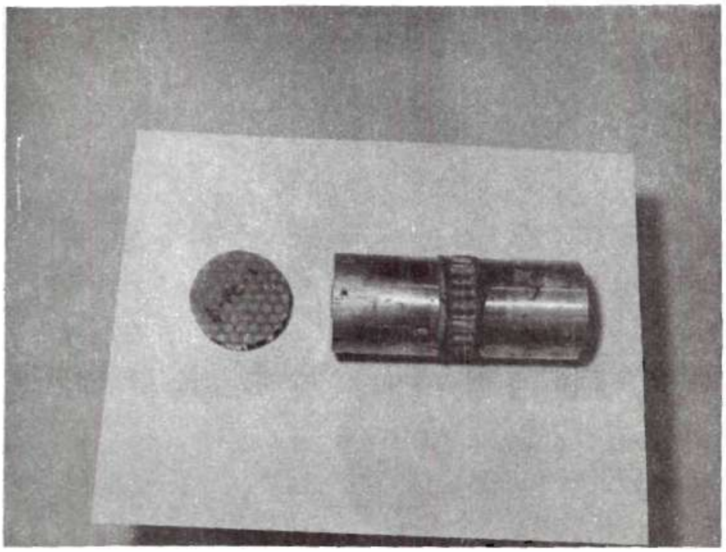


Figure 13. Sandwich Flatwise Tension Specimen

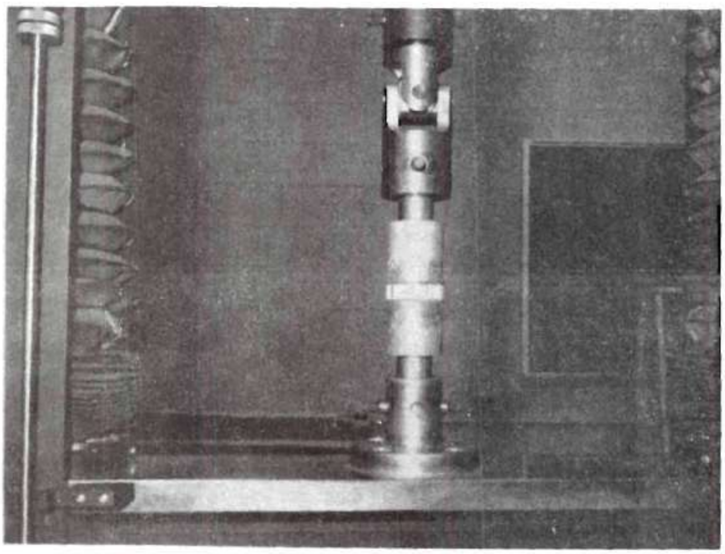


Figure 14. Sandwich Flatwise Tension Test

Flatwise Compression

Flatwise compression tests were performed following ASTM C365-57 [25]. Specimens from each core size and identical to the flatwise tension ones were used for this test. They were placed on a spherical seat and aligned parallel to the ram mounted on the bottom of the crosshead. Loading was accomplished at 0.002 inch/minute. Strength results and failure mode were recorded.

Flexural Shear

The flexure test to produce core shear failure has been relatively standardized and accepted, following the methods of ASTM C393-62 [26]. However, since sandwich with relatively thin fiberglass reinforced plastic face sheets were being tested, the load points were changed from the one-half-inch diameter described in the ASTM method to three-fourths-inch flat pads on one-eighth-inch radius load points. This precluded failure under the load points, yet did not interfere with the deflection characteristics of the specimen under load. The specimens were the standard size, three inches by eight inches, loaded using the four-point loading method. The top load points were spaced two inches; the bottom points were spaced six inches; allowing one-inch overhang on each end. A small L-shaped wire was inserted into the core in the midplane of the midsection, following the practice described in the ASTM method. The Instron G-51-14 extensometer was used as a deflectometer by attaching the movable leg to the wire. Figure 15 shows the test setup. The tests were conducted at 0.05 inches per minute crosshead speed. Load versus center deflection was recorded on the Instron chart for later evaluations of core shear modulus, core shear strength, and face stress. Failure modes were recorded.

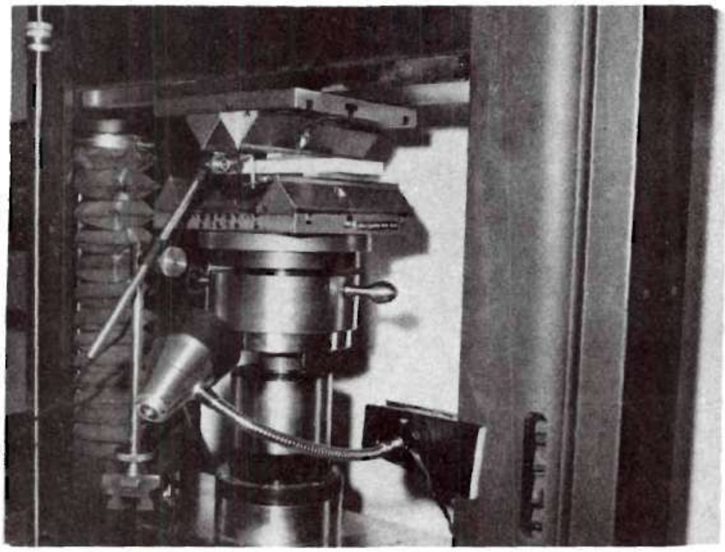


Figure 15. Sandwich Flexural Shear Test

Sandwich Edgewise Compression Tests

Edgewise compression tests were performed similarly to the methods described in ASTM C364-61 [19]. Prior experience, industry recommendations and available equipment dictated changes in end support clamps, specimen end preparation and testing alignment methods.

The sandwich specimens were rough cut in the desired orientation from the panels, using the Remington bandsaw. The ends were filled with a room temperature curing filled epoxy potting compound, Magnolia Plastics, Chamblee, Georgia; Magnobond 79-3. The core between the face sheets was routed out along the width to a depth of one-half inch, using a table circular saw dado blade and spacer. The core was left bonded to the inside of the face sheets to a depth of one-sixteenth inch to keep the adhesive fillet stiffness pattern intact, insure no cutting into the face sheet, and provide a tie from the potting compound to the core. The potting compound was carefully cast into the routed-out area avoiding entrapment of air. Care was also applied to keep the face sheets spanning the routed core area parallel while the potting compound cured. The specimens were then clamped in an alignment fixture and the ends machined flat and parallel. This operation machined about 0.1 inch of the ends of the face sheets. The sides were hand-sanded smooth. Figure 16 shows the test specimen.

In order to load the specimens and strain the two faces uniformly, a spherical seat and flat strap-like end clamps were installed on each specimen finger tight, loosening and tightening the wing nuts in rotation to eliminate any wedging action on the ends of the specimen. The clamps were three-fourths-inch deep and supported the face sheets to one-fourth

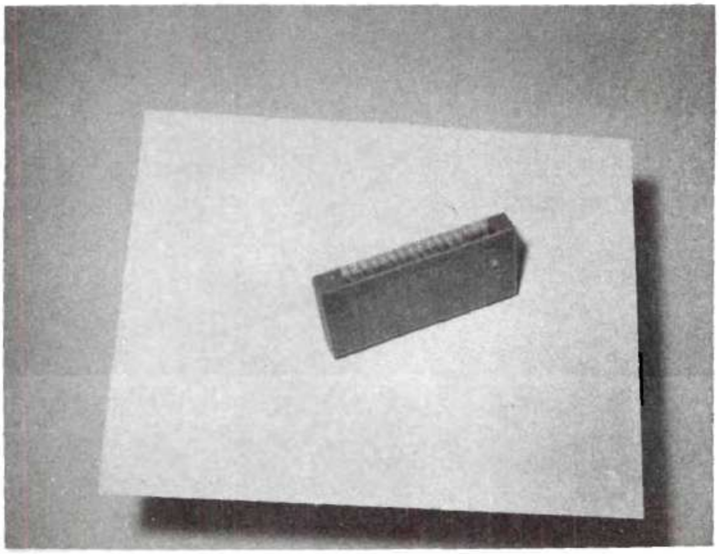


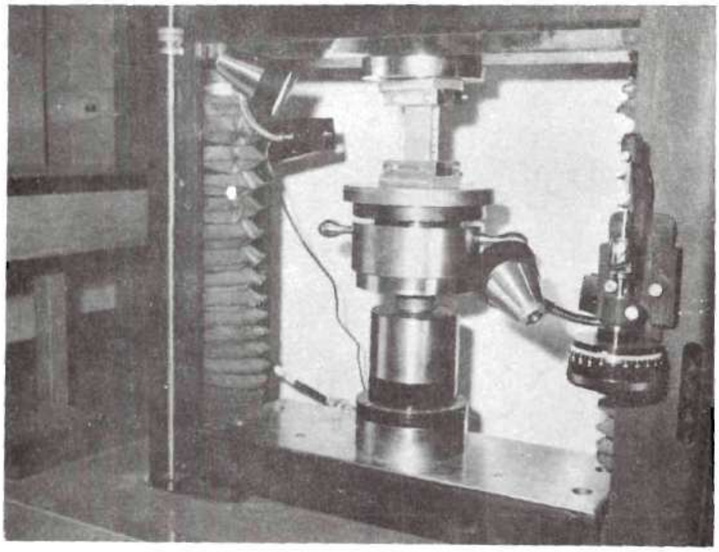
Figure 16. Sandwich Edgewise Compression Test Specimen

inch above the potting compound. The specimen with end clamps was placed on the spherical seat and the crosshead was lowered to within approximately 0.05 inch of the top of the specimen. Visual indications of misalignment were corrected by manual adjustments of the spherical seat until load was normal to the specimen. Figure 17 shows the test setup. Load was applied at 0.02 inches/minute.

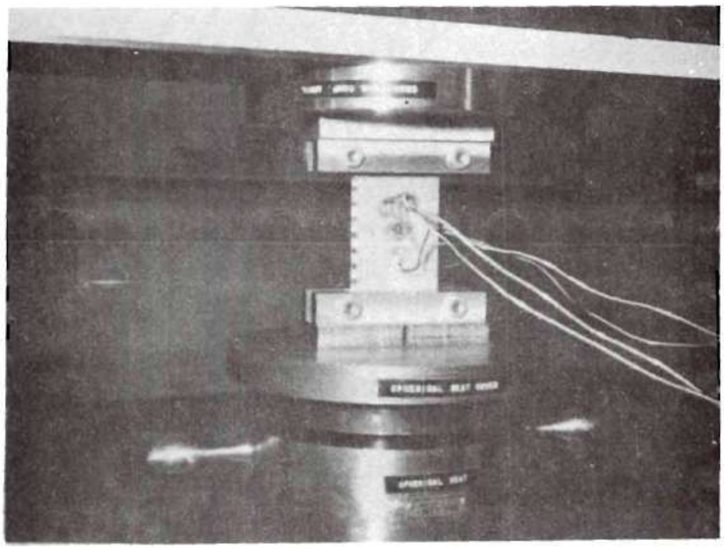
One sample from each size and orientation was tested to verify test procedure and indicate expected load levels and failure modes. It was demonstrated that face sheet failure could be expected for every type specimen. Interest was then generated in covering the surface with a photo-stress coating and examining the response of the face sheets under load to verify uniformity of load input and the belief that no stability modes were being reached.

The photoelastic coatings were applied on both face sheets of selected specimens by personnel at Photolastic, Inc., using their standard techniques. The specimens were loaded using the standard described techniques and examined under polarized light at various percentage of expected ultimate loads. Thirty-five millimeter slides were taken at these increments.

With the indications that the loading was even, selected specimens were strain gaged to again ascertain whether the face sheets were being strained uniformly and to determine principal strains and the elastic constants of the faces under the loading. Three arm rectangular rosettes were installed on both sides of each selected specimen, using standard application techniques as recommended by BLH Electronics, the manufacturer of the strain gages. Eastman 910 adhesive was used to bond



Strength Test



Specimen with Strain Gage Rosettes

Figure 17. Sandwich Edgewise Compression Test

Strain Indicating Instruments

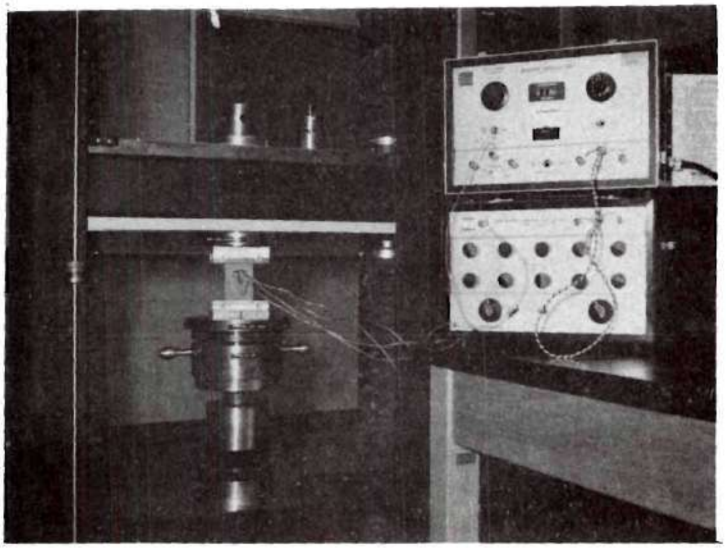


Figure 17. Continued

the gages to the fiberglass reinforced plastic face sheets. The strain readings were obtained from a BLH switch and balance unit hooked to a BLH strain indicator. The load was held at each reading.

All the remaining specimens were tested uninstrumented to provide a statistical basis for determining the ultimate strengths. The same procedures for clamping the ends and aligning the specimen on the spherical seat were used. Failure modes and failure loads were recorded.

CHAPTER IV

EXPERIMENTAL RESULTS AND EVALUATION

The experimental results are discussed according to the type of experiment and mode of failure.

Facing Laminate Properties

Tests were performed on 12 ply laminates to determine the tension and compression strengths and moduli at 0°, 45° and 90° to the warp direction. The test data are recorded in Appendix 2, Section 1. The results are tabulated in Table 1. Following the guide of MIL-HDBK-17 [27], a set of equations was developed to accept the strength and modulus values of the 45° load angle in lieu of the shear modulus and shear strength which were then calculated and reinserted into the MIL-HDBK-17 equations. These equations then were solved to provide the modulus and strength values of the laminate at every five degree increment from the major warp axis. The equations and a computer program used to perform the calculations are presented in Appendix 3, Section 1.

Results from the 12 ply tension and compression tests at 0°, 90° and 45° were input into the program to yield the strengths and moduli at every five degree increment from the warp direction for tension, compression and shear. An input value of Poisson's ratio was required. A value of 0.17 was reported in Reference 28, for 13 ply laminates fabricated from 181 style fabric with Epon 828/CL epoxy resin system. However, more recent data, [29], on 75DE181/Narmco 500 material, a material

Table 1. Facing Laminate Tension and Compression Properties (12 Ply, BP919/75DE181)

Load Angle to Warp Direction	Tension		Compression	
	Strength (psi)	Modulus (psi)	Strength (psi)	Modulus (psi)
0°	59,800	3.19×10^6	64,100	3.55×10^6
30°			23,600	2.04×10^6
45°	26,800	1.71×10^6	21,600	1.73×10^6
60°			23,200	2.21×10^6
90°	41,100	2.98×10^6	50,500	3.31×10^6

identical to the 75DE181/BP919 material being investigated, indicated Poisson's ratio should be 0.16. This value was used in the above calculations.

Data points to the laminate compression tests at 30° and 60° were obtained to check the computer output and compared with the output in Table 1. The results of the tension and compression 12 ply laminate tests and computerized load angle analysis are presented in Figures 18 and 19. These are polar graphs indicating tensile, compressive and shear strengths and moduli at all orientations from the basic warp direction.

In order to compare the 12 ply laminate properties to those of the three ply face sheets, reductions in strength and modulus were required. Basically, such reductions are empirical; however, they are thought to be caused by such factors as that in a three ply laminate, a greater percentage of the plies are on the surface which contain micro-voids and damages and are not as efficient as interior plies. MIL-HDBK-17, [27], provides data for tensile and compressive strength reductions from 12 ply to three ply laminates fabricated from 181 style fabric and Scotchply 1002 epoxy resin. The three ply compression values are 81 percent of the 12 ply values.

Recently, certain unpublished data on 75DE181/E293 epoxy laminates generated at Lockheed-Georgia, substantiated empirical reductions proposed in Reference 30. These calculations provide the following reductions of 12 ply laminates to three ply laminates:

3 Ply Compressive Strength = 90% of 12 Ply
3 Ply Tensile Strength = 91.4% of 12 Ply
3 Ply Compressive Modulus = 96.9% of 12 Ply
3 Ply Tensile Modulus = 93.1% of 12 Ply

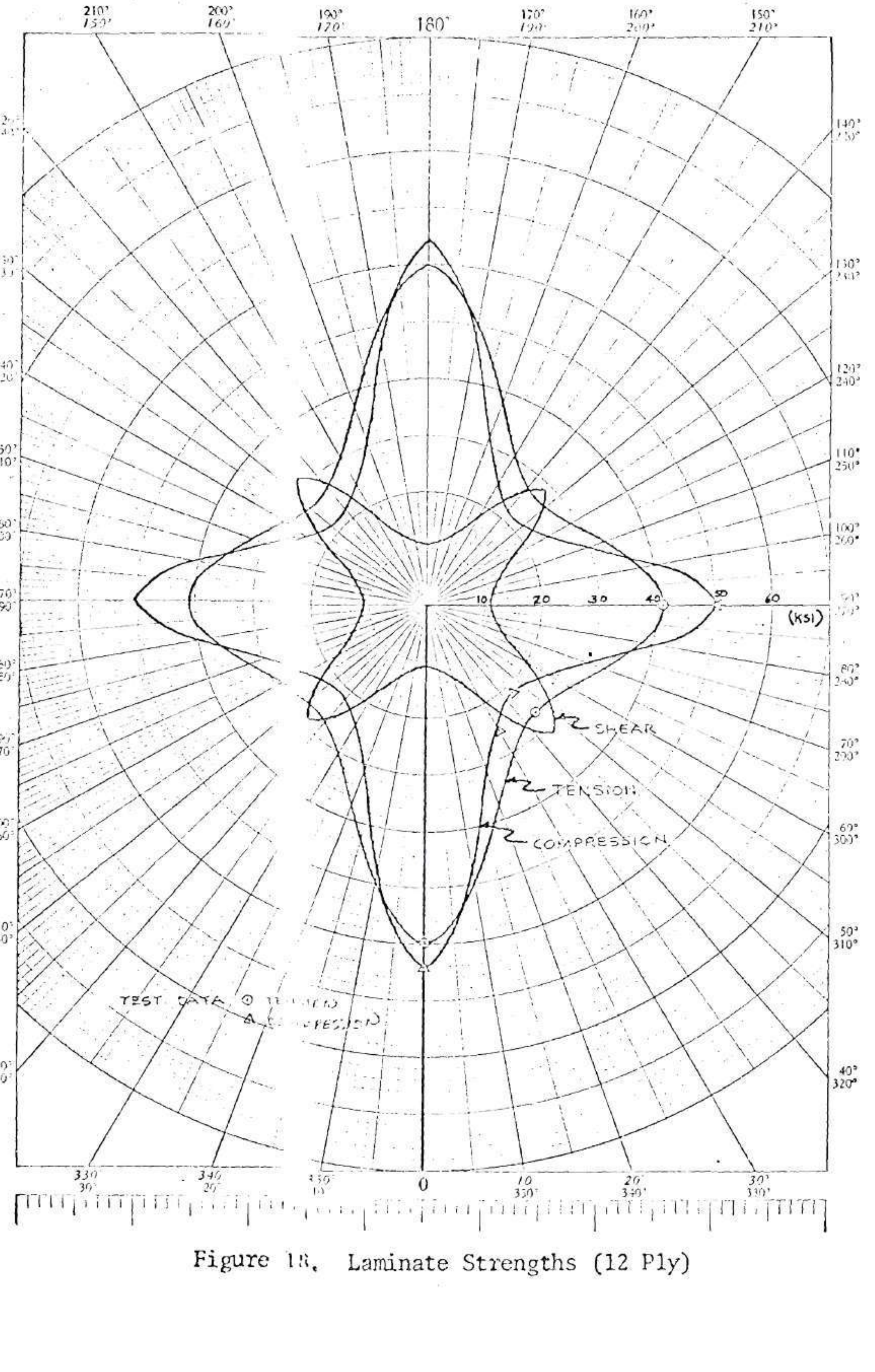


Figure 18. Laminate Strengths (12 Ply)

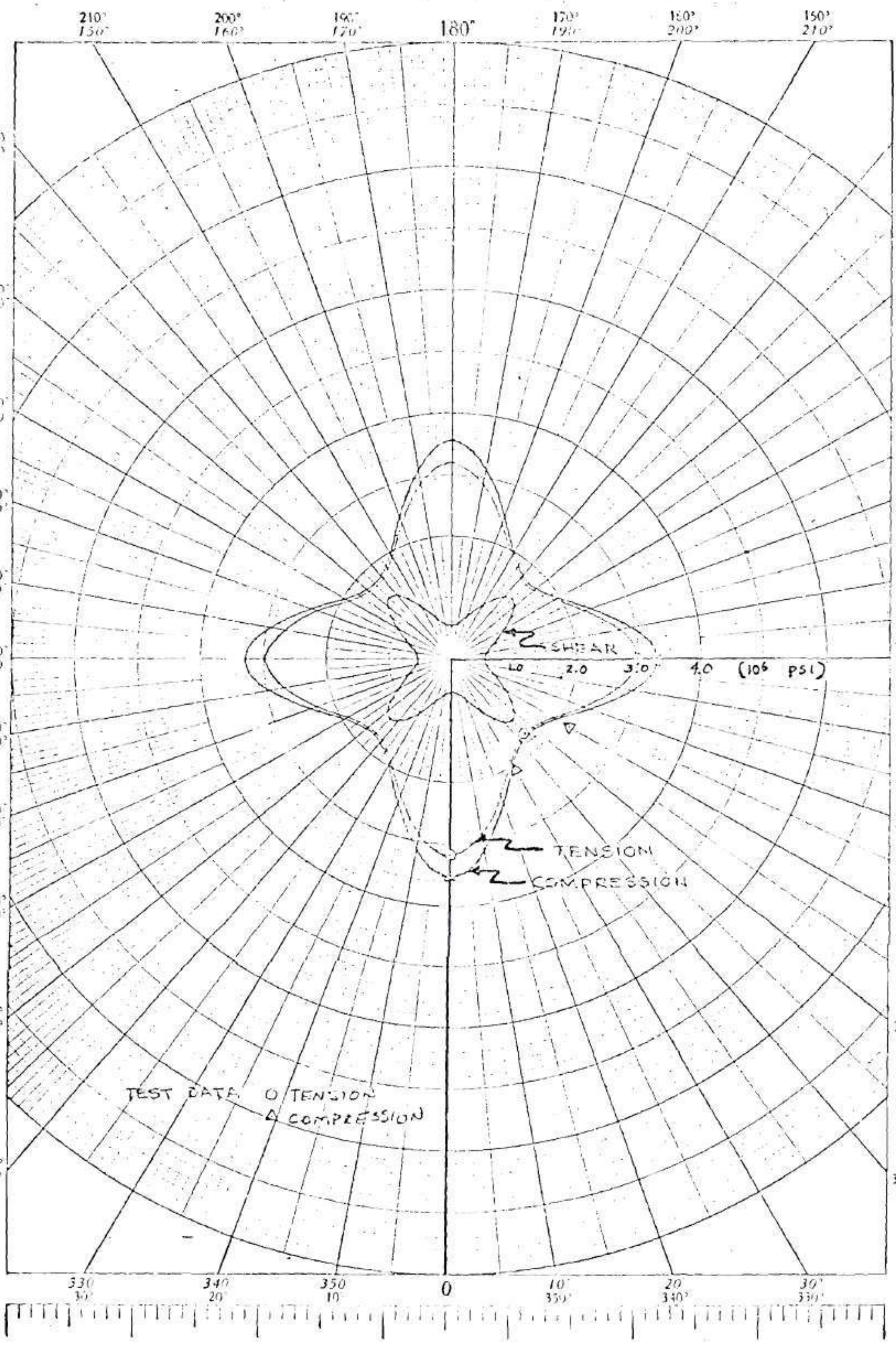


Figure 19. Laminate Moduli (12 Ply)

Using the above two referenced recommendations, the following criteria were followed for reducing 12 ply to three ply data:

3 Ply Tensile and Compressive Strengths = 90% of 12 Ply
3 Ply Tensile and Compressive Modulus = 95% of 12 Ply

The input strength and modulus values were reduced by these amounts and input into the computer program. The resulting three ply tensile, compressive and shear strengths and moduli for all orientation angles are presented in Figures 20 and 21. These data represent the face sheet material properties.

Laminate Quality Control Tests

Certain other data were developed to ascertain that the laminates being tested for tensile and compressive properties were of high quality and represented typical aircraft type laminates. To a certain degree, the tension and compression tests indicated the laminates were adequate; however, flexure tests and void volume calculations were needed to complete the description of the laminate.

The flexure test, although meaningless as a design property test, yields comparative data indicating the resin performance of the laminate. Low values of flexural strength (modulus of rupture) indicate a low interlaminar shear capability of the laminate caused by insufficient resin action, possibly caused by poor resin cure, poor resin formulation, old resin material or other fabrication problems. Void content indicates entrapped air which can be deleterious to the laminate performance.

The flexural tests were performed on the 12 ply panels provided by American Cyanamid. Additional tests were also performed on two additional panels of the same material fabricated by Lockheed-Georgia Company

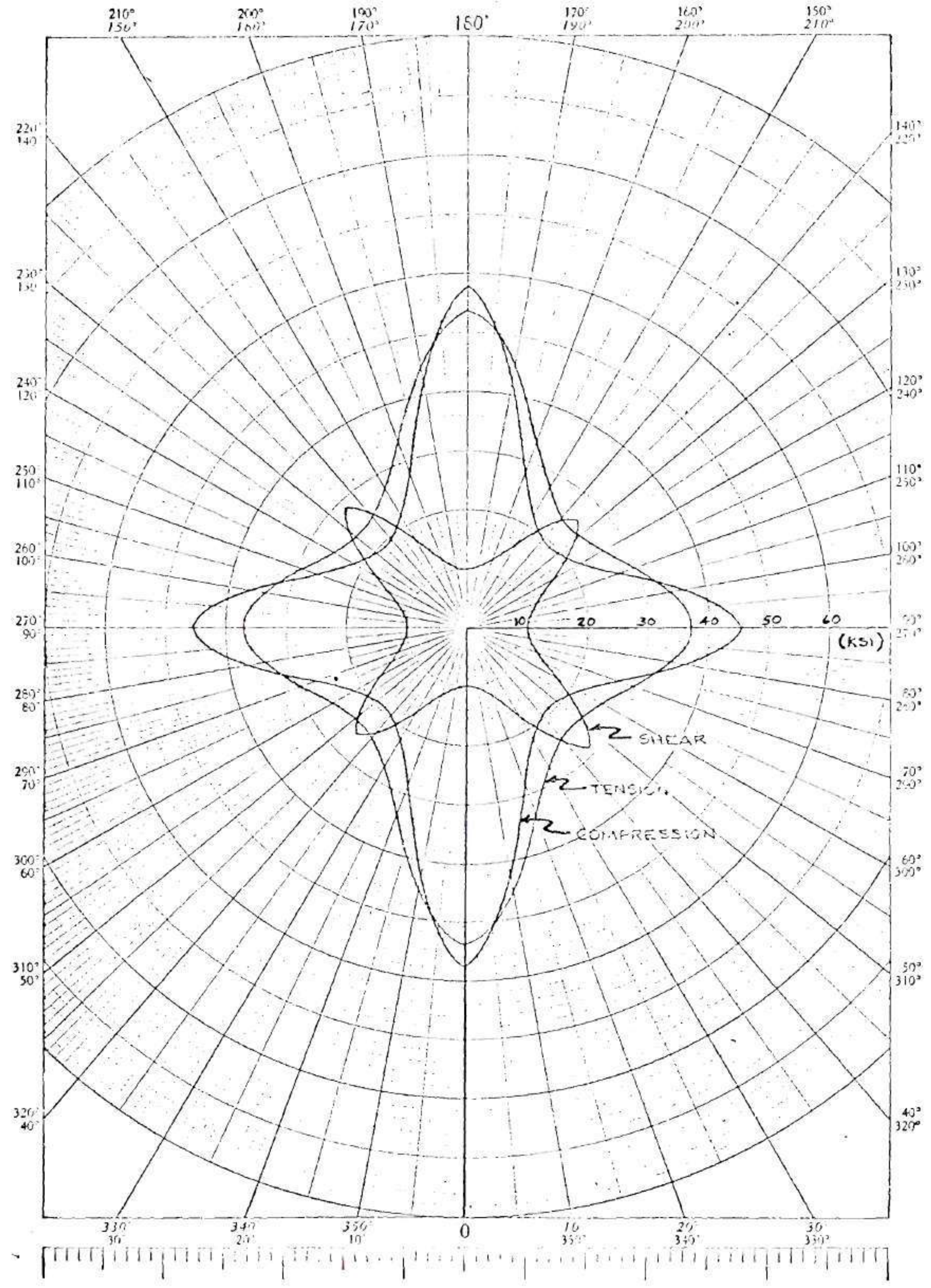


Figure 20. Laminate Strengths (3 Ply)

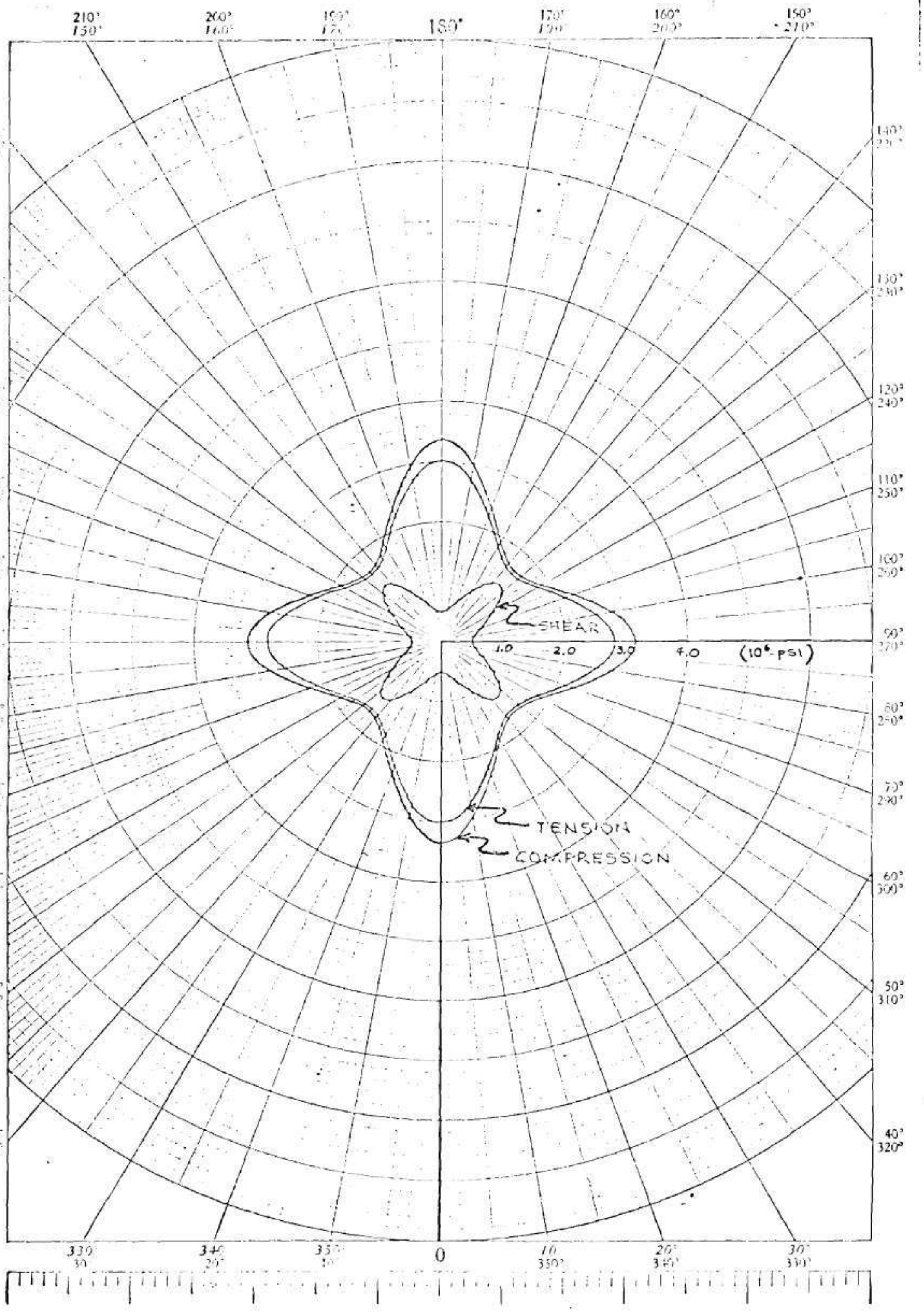


Figure 21. Laminate Moduli (3 Ply)

and on panels of similar material (75DE181/SP275A) provided by the 3M Company. The flexural strength (modulus of rupture) and flexural tangent modulus were calculated according to the small deflection analysis described in ASTM D790-66:

$$\text{Modulus of Rupture} = \frac{3(\text{Load})(\text{Span})}{2(\text{Width})(\text{Thickness})^2}$$

$$\text{Tangent Modulus} = \frac{(\text{Span})^3(\Delta\ \text{Load})}{4(\text{Width})(\text{Thickness})^3(\Delta\ \text{Deflection})}$$

The test data are presented in Appendix 2, Section 1, and the results are tabulated in Table 2. The modulus of rupture values indicate high overall quality of the panels used to develop the laminate tension and compression data.

The laminates were tested for percent resin content by weight (37%) and specific gravity (1.95) and reported by the manufacturer. The cured BP919 resin specific gravity value of 1.40 ±.02 was also reported by the manufacturer and used along with the known and well documented specific gravity figure of 2.54 for E glass as reported by Owens Corning [31]. These values were used to calculate the percent void volume according to the equation of Reference 23:

$$\%\ \text{Void Volume} = 100 - \left(\nu_{\text{Laminate}}\right)\left[\frac{\%\ \text{Resin Content}}{\nu_{\text{Resin}}} + \frac{\%\ \text{Glass Content}}{\nu_{\text{Glass}}}\right]$$

where ν is the specific gravity and the percent resin content and percent glass content are measured by weight.

The percent void volume for the laminate was 0.1%, which indicates a very dense quality laminate.

Table 2. Facing Laminate Flexural Properties (12 Ply)

Test Panel Description and Manufacturer	Flexure	
	Modulus of Rupture (Strength) (psi)	Modulus of Elasticity (psi)
BP919/75DE181 Panel B-108-4 American Cyanamid Co.	83,500	3.16×10^6
BP919/75DE181 Panel A306684 Lockheed-Georgia Co.	87,000	3.48×10^6
SP275A/75DE181 Panel X-3 3M Company	84,100	3.32×10^6

Sandwich Quality Control Properties

The sandwich quality control tests served two purposes. They provided a base to determine if the fabricated sandwich panels were sound; and they provided constituent properties needed in analysis of the edgewise compression results. The flatwise tension tests provided core tension properties or tensile adhesive bond properties, whichever was less; the flatwise compression tests provided core compression properties. Such data was required for a face wrinkling analysis of the edgewise compression test. The flexural shear test provided core shear properties needed in a shear stability analysis of the edgewise compression test. The flexural shear test also provided enough data to derive an effective stiffness of the sandwich structure.

Flatwise Tensile Test Results

Five specimens from panels of each cell size (1/8", 3/16" and 1/4") were tested in flatwise tension. Test data are listed in Appendix 2, Section 2. The results are presented in Figure 22 as a function of core density (related to core cell size) and flatwise tensile strengths. The light weight, 3.7-pound-per-cubic-foot (1/8" cell) core failed in tension as a rupture of the core material. The other two heavier cores failed as adhesive bond failures of the core to the face sheets. The lower results of the 6.8-pound-per-cubic-foot (3/16") core was evident when inspecting the bond failure. The fillet to the core was smaller and did not break as large amount of adhesive away from the face sheet as did the 8.0-pound-per-cubic-foot (1/4") core. Figure 23 compares the three failures. The test results indicate quality adhesive bonds.

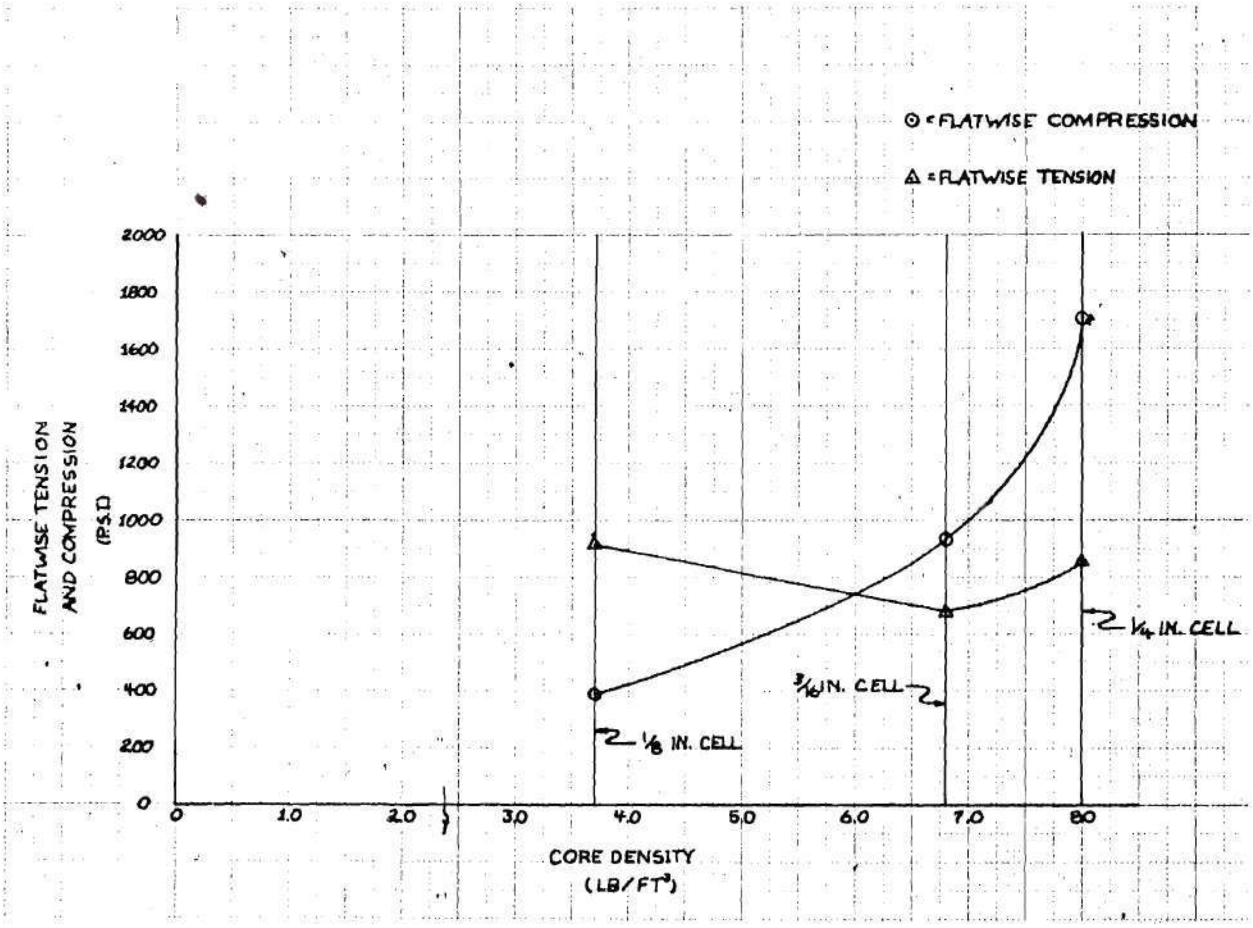


Figure 22. Sandwich Flatwise Strengths

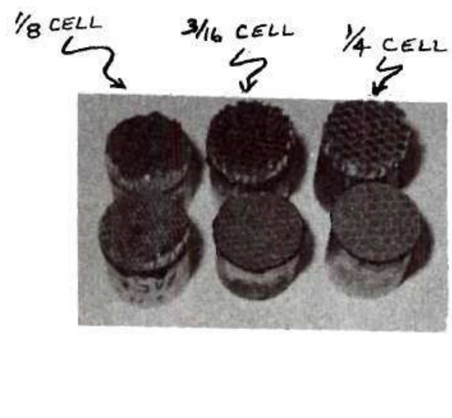


Figure 23. Sandwich Flatwise Tension Failures

Flatwise Compressive Test Results

Five specimens from panels of each cell size were tested in flatwise compression. Because the cell edges were stabilized by the face sheets of the bonded sandwich, failure was expected to occur as a buckling of the cell walls. Such compression strengths would be higher than those obtained from tests on base core, but would be more realistic when used in a face wrinkling analysis. As expected, all failures were of the core walls buckling. The test data is presented in Appendix 2, Section 2, and the results presented in Figure 22.

Flexural Shear Quality Control Test Results

Five specimens at 0° load angles cut from panels of each cell size were tested in flexural shear to provide base data for quality control checks of panels to be used for edgewise compression specimens.

The 1/8" and 3/16" core specimens failed in core shear stress; however, the 1/4" core specimens failed the upper face sheet in a laminate compressive strength mode. The test data is presented in Appendix 2, Section 2. The results are presented in Table 3. Also presented in Table 3 are the results of the 0° quality control flexure tests of samples from each panel used for edgewise compression tests. All the panels behave as expected with the exception of panel 158-13, a 1/4" core panel used for 0° load angle edgewise compression tests. The failure mode was a face sheet compressive strength failure as expected for 1/4" core; however, the face sheet stress values were slightly lower than expected. The flexural quality control test data are presented at the end of Appendix 1, along with the quality control part riders that accompanied each panel through fabrication at American Cyanamid.

Table 3. 0° Flexural Shear Sandwich Strength Results

Test Description	Cell Size	Panel Number	Core Shear Stress (psi)	Face Stress (#/in. width/face)
Quality Control Data Developement	1/8	BP919-158-16	233	
	3/16	BP919-113-10	473	
	1/4	BP919-158-6		1158
Panel Quality Control (Edgewise Compression Panels for Load Angles)				
0°	1/8	BP919-158-2	265	
30°	1/4	BP919-158-5		1207
90°	1/4	BP919-158-7		1363
45°	1/4	BP919-158-9		1346
60°	1/4	BP919-158-12		1246
0°	1/4	BP919-158-13		1032
90°	1/8	BP919-158-15	267	
45°	1/8	BP919-158-17	256	
60°	1/8	BP919-158-18	239	
30°	1/8	BP919-158-20	254	
45°	3/16	BP919-113-3	525	
60°	3/16	BP919-113-4	523	
30°	3/16	BP919-113-7	508	
90°	3/16	BP919-113-8	531	
0°	3/16	BP919-113-9	526	

Sandwich Flexure Stiffness and Strength Results

These tests provided an abundance of data available not only for calculating shear stress across the core and face sheet stress, but for also calculating effective stiffness and effective modulus of the three ply face sheets.

Using a flexure analysis such as that presented in Appendix 4, the data used to develop the base comparative data for quality control purposes were also used to investigate the effective stiffness and effective modulus. Using the load and center deflection values obtained from the Instron recorded output, an experimental (EI) was calculated for the sandwich. Using the shear deformation analysis, the shear deflection was calculated and subtracted from the measured center deflection. The corrected bending deflection was then used to recalculate the experimental (EI). This value was then divided by an (I) calculated from the sandwich configuration. This resulting effective E is compared to the laminate three ply values acquired earlier in the testing in Table 4.

Another comparison readily available from the flexure tests involves the face sheet compressive strength calculated from the results of the 1/4" cell size flexure specimens which failed in a face sheet strength failure mode. Table 4 compares the calculated 0° face sheet compressive strength from the flexure test, and the reduced three ply 0° laminate compression tests. Finally, an equivalent (EI) was calculated based on the methods of Reference 32 and Reference 33 and presented in Appendix 4. The calculations are also presented in the Appendix. The effective EI and experimental EI are compared in Table 5.

Table 4. Comparison of Three Ply Laminate Properties (Compression) as Determined by Reduced 12 Ply Laminate Tests and Sandwich Flexure Analysis

Three Ply Reductions of 12 Ply Laminate Tests		Sandwich Flexure Test Results	
Strength (psi)	Modulus (psi)	Strength (psi)	Modulus (psi)
57,700	3.35×10^6	38,600	4.87×10^6

Table 5. Comparison of Experimental and Calculated Stiffness of the Sandwich Flexural Shear Tests

	Sandwich Flexure Stiffness Results		
	1/8 Cell	3/16 Cell	1/4 Cell
(EI) ($lb\text{-}in^2$) Experimental	34,500	38,300	40,400
(EI) ($lb\text{-}in^2$) Calculated	26,500	31,200	29,600

Edgewise Compression Tests

At the initiation of the experimental investigation, certain ground rules were established concerning the design of the edgewise compression specimens and the anticipated failure modes. Typical aircraft type construction was chosen which dictated core densities of from three pounds per cubic foot to eight pounds per cubic foot. Three ply 75DE181 face sheets were chosen as typical lighweight non-metallic facings.

General Buckling

The edgewise compression specimen was designed as a short column precluding failure in a general instability or Euler buckling mode.

Intracellular Buckling

The maximum core cell size was limited to 1/4 inch as the largest typical cell size used in aircraft design for such lightweight structure. This requirement should have precluded concern about the intracellular or dimpling type failure mode. According to Reference 18, an empirical approximation of the critical buckling stress of the facings spanning the voids between the cell walls is proportional to the square of the facing thickness divided by the cell diameter.

The most critical condition for this empirical relation would be provided by the 1/4 cell diameter oriented at 45° to the ribbon/warp direction where the modulus would be the lowest. Using the equation out of Reference 18:

$$\sigma_{cr} = 2\left(\frac{E1}{1-\nu^2}\right)\left(\frac{t_f}{S}^2\right)$$

Where E^1 is the effective elastic modulus of the facing material in the direction of the loading which in this case could be taken as the reduced three ply 45° compressive modulus of 1.64×10^6 psi; t_f is the face sheet thickness, which for three plies can be approximated by 0.03 inches; S is the diameter of the core cell which can be approximated by 0.25 inch; and ν is the Poisson's ratio which later instrumented edgewise compression tests at 45° yielded values approximating 0.6. This yields a critical facing stress of 73,800 psi or 2,214 pounds/inch-width/face which is higher than any expected face stress that the face sheet can withstand prior to strength failure. However, it should be noted that this stress is within a factor of three or four of the expected ultimate strength and possibly more accurate empirical methods should be developed for orthotropic face sheets.

Face Wrinkling

According to Reference 14, face wrinkling can be predicted for two ply or three ply fiberglass faces using the theoretical basis developed in References 4 and 9. These theoretical developments are lengthy and complex; however, certain salient points can be gleaned from the examination of the assumptions and conclusions. Namely, the face wrinkling phenomenon is thought to be dependent upon an initial waviness which is a function of the core cell size and, in the case of fiberglass reinforced plastic face sheets, the fabrication method. This occurs because during fabrication, pressure is applied to laminate the face sheet upon the core, and the pressure is reacted by the ends of the core cell walls. This causes the facing thickness to be less at these core cell wall locations and greater over the center of the cells even though the outside surface is relatively flat. Other assumptions in the theoretical developments concerned the directional relations of core properties. A K factor was presented that related the core elastic properties with the notation that this factor must be smaller than 0.5 at which time the dimension of the half wave length of the face wrinkles (L) may be taken equal to the cell size of the core. According to calculations presented in Reference 14, this parameter, K, is small for honeycomb cores suitable for aircraft construction and is calculated equal to 0.05 for two pounds per cubic foot core. With these assumptions, the simplified equation presented in Reference 9 can be used.

$$\sigma_{cr} = \left(\frac{\pi^2}{12}\ \frac{t_f^2\ E_f}{L^2 \lambda_f}\right)\left[\frac{1 + \left(\frac{24}{\pi^4}\ \frac{E_{cz}\lambda_f}{E_f}\ \frac{L^4}{t_c\ t_f^3}\right)}{1 + \left(\frac{2}{\pi}\ \frac{E_{cz}}{t_c}\ \frac{L\ K_o}{T}\right)}\right]$$

Where t_f = face thickness

t_c = core thickness

λ_f = unity minus the product of the two Poisson's ratios of the facing material associated with the axes aligned with the edges of the specimen

E_{cz} = modulus of elasticity of the core parallel to the cell axis

L = half wave length of facing wrinkles, here equal to cell size

E_f = facing modulus and taken by Nordby [14] to be the facing modulus parallel to the test axis

K_o = ratio of the facing wave amplitude to half wave length at no load (initial waviness)

T = tensile strength of core (or bond) in direction perpendicular to the facings

Since face wrinkles are free to move in or out, perpendicular to the faces, depending on the reaction of least resistance, the factor T should actually be the least absolute strength value of the flatwise compression and flatwise tension results where the flatwise tension tests will already determine the least strength value between the core tensile strength and the adhesive bond strength.

All the prior testing has determined all the needed values for the face wrinkling equations except the value of K_o. Visually, no discernible external initial waviness is present; however, after flatwise tension tests, inspection of the internal surface of the face sheets allowed estimates of the amplitude of the facing wave to be approximately one ply thick, or 0.01 inch for the 3/16 core; approximately one and one-half plies thick, or 0.015 for the the 1/4 core; and undiscernible for the 1/8 core. This would provide the following K factors (assuming a linear amplitude relationship for calculating the 1/8 core value):

1/8 core	$K_o = .04$
3/16 core	$K_o = .053$
1/4 core	$K_o = .06$

For each type core, all the face wrinkling parameters are constant at any load angle except Poisson's ratio and modulus of elasticity of the facing material. Calculations were performed using the computer program in Appendix 3, Section 2, to predict the face wrinkling at 0°, 30°, 45°, 60° and 90° using the three ply compression modulus values and Poisson's ratios later obtained in the instrumented edgewise compression tests. The results are presented in Table 6. Interestingly, the face wrinkling stress for any particular case remains almost constant for varying load angles. As the modulus decreases as the load angle changes, the Poisson's ratio increases holding the stress relatively constant. These face wrinkling stresses were within the range of the 0° load angle edgewise compression samples prior to a face sheet strength failure. The off angle specimens were not expected to carry such high load levels prior to failure.

Shear Crimping

The other possible stability failure is the shear crimping mode. According to Reference 9 (the use of which is recommended by Reference 14), the shear crimping stress is proportional to the core shear modulus values at the load orientation, and independent of the face sheet properties. The stress is calculated by the equation:

$$\sigma_{cr} = (.5)\,\frac{t_c}{t_f}\,G_{cxz}$$

Where t_c is the core thickness,

t_f is the facing thickness,

and G_{cxz} is the core shear modulus in the plane parallel to the load angle (x), and normal to the face sheets (z).

Since the face sheets were nominally 0.03 inches thick and the core

Table 6. Face Wrinkling Stress Determined by Cell Size and Load Angle

Core Cell Size	Load Angle	Face Wrinkling Stress (lb./in.-width/face)
1/8	0° 30° 45° 60° 90°	1447 1265 1307 1242 1369
3/16	0° 30° 45° 60° 90°	963 908 919 903 934
1/4	0° 30° 45° 60° 90°	1145 1127 1131 1125 1137

nominally 0.5 inch thick, the equation becomes:

$$\sigma_{cr} = 8.33\ G_{cxz}$$

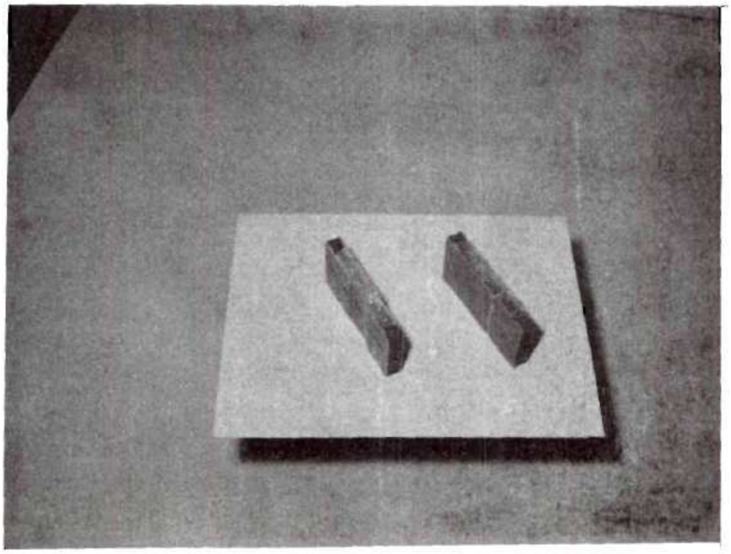
Reference 34 provides values for G_{cxz} where $x = 0°$ and $90°$. These values are tabulated in Table 7 along with the calculated shear stability stresses. The 90° modulus should be the lowest obtainable value for any core and the 1/8 inch core, because it is the lowest in density, should provide the lowest value of the three cores. The results in Table 7 indicate no shear crimping should occur even for the 1/8 inch, 90° specimens. However, this was not the case. Shear crimping failures occurred on some of the 1/8 inch cell 90° specimens. Sufficient specimens failed in this mode to allow a statistical average to be computed. The statistical averages will be explained in the next section. However, a statistical average value of 691 pounds/inch-width/face was recorded for 1/8 inch cell, 90° load angle edgewise compression specimens that failed in a core shear crimping instability mode. Identical specimens that exhibited compressive face sheet strength failure recorded a statistical average value of 747 pounds/inch-width face. The test data and statistical reduction calculations are combined with those of the strength tests discussed in the next section. The test data appears in Appendix 2, Section 3. Figure 24 shows the two types of failure modes for the 90°, 1/8 inch cell specimens. Better measurements of core shear modulus at varying angles to the ribbon direction and improved shear instability analyses are definitely needed.

Photoelastic Investigation

Initially, one sample from each type core and each load angle was

Table 7. Shear Crimping Failure Strength Prediction

Core Description		0° Orientation		90° Orientation	
Cell Size (Inch)	Density (lb/cu.ft.)	G_{xz} Core (psi)	$\sigma_{cr_{0°}}$ (#/in.-width/face)	G_{yz} Core (psi)	$\sigma_{cr_{90°}}$ (#/in.-width/face)
1/8	3.7	40,000	10,000	20,000	5,000
3/16	6.8	72,000	18,000	41,000	10,300
1/4	8.0	115,000	28,800	50,000	12,500



Shear Crimping Failure

Facing Strength Failure

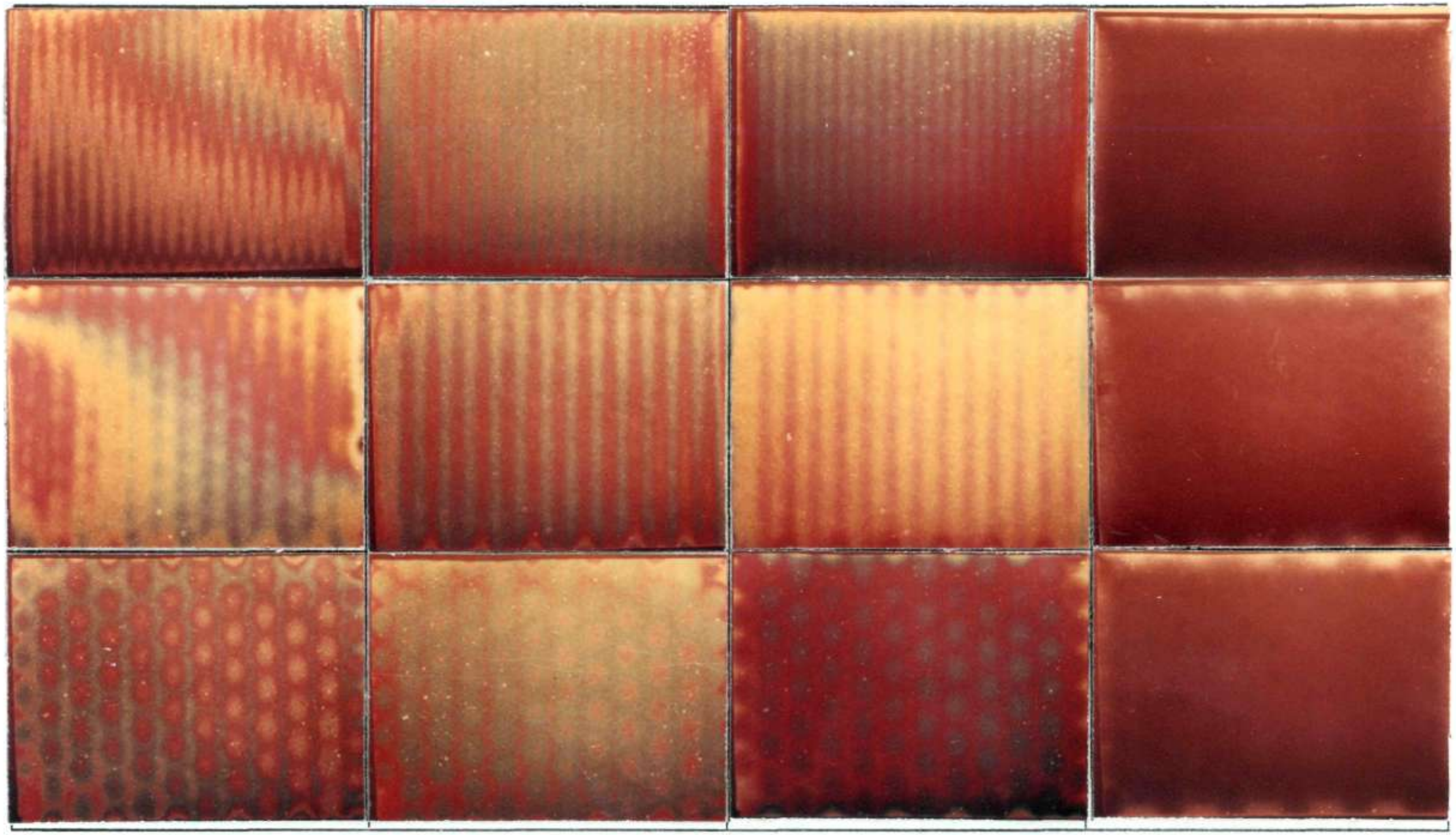
Figure 24. Sandwich Edgewise Compression Failures of 90° Oriented, 1/8 Cell Specimens

tested in edgewise compression to ascertain expected failure modes and strength levels. The results indicated all the load angle/core size combination would result in face sheet compressive strength failure. No visual stability responses were observed. A method was desired to verify these conclusions. This problem and several other problems were solved with the use of a photoelastic coating on selected edgewise compression specimens. Not only were the visual clues to any instability action "magnified," but also the loading pattern across the face sheet and the effect of core size and density on the loading response were evident. Zero degree and 45° specimens of 1/8, 3/16 and 1/4 inch core size were coated and investigated under the action of polarized light. Pictures were taken at increments of the expected ultimate load and viewed in sequence to demonstrate the loading pattern. Several conclusions were drawn. Spanning over the voids of the 45° large (1/4") cell core specimens, a strain differential of greater than one fringe value existed for the highly loaded condition. This could indicate an incipient intracellular buckling phenomena. The 0° medium (3/16) cell core specimens exhibited strain patterns constant across the width, but varying in ripples down the length in conjunction with the cell size which could indicate incipient face wrinkling. The small (1/8) lightweight core reacted to the loading in a method reminiscent of a homogeneous, soft, foam-like core. These observations were made in addition to the recognition that the specimen is very susceptible to misalignment and uneven loading. Techniques were developed during these investigations to align the specimen properly, using the spherical seat.

EDGEWISE COMPRESSION PHOTOELASTIC PHOTOGRAPHS (→ Load Direction ←)

Axial Compression Load Applied 0° to Warp/Ribbon Direction

(75%) $\sigma_{ultimate}$ | (50%) $\sigma_{ultimate}$ | (25%) $\sigma_{ultimate}$ | (0%) $\sigma_{ultimate}$



1/8" Cell

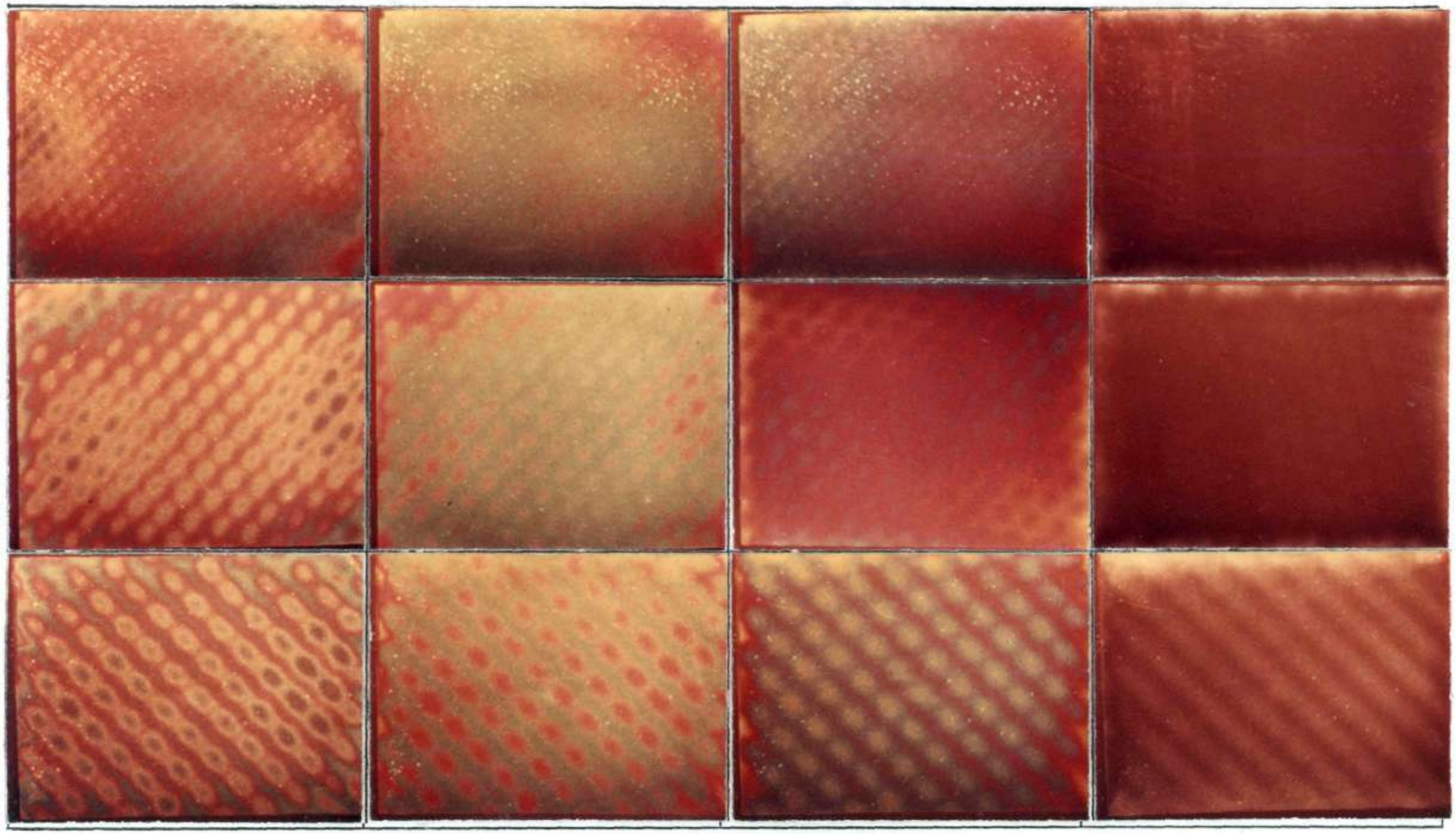
3/16" Cell

1/4" Cell

EDGEWISE COMPRESSION PHOTOELASTIC PHOTOGRAPHS (→ Load Direction ←)

Axial Compression Load Applied 45° to Warp/Ribbon Direction

(75%) $\sigma_{ultimate}$ | (50%) $\sigma_{ultimate}$ | (25%) $\sigma_{ultimate}$ | (0%) $\sigma_{ultimate}$



1/8" Cell

3/16" Cell

1/4" Cell

Edgewise Compression Strength and Modulus Tests

Since the stability failures were not likely to occur, information was desired as to the use of the edgewise compression specimen as a test device for determining the strength and stiffness properties of the thin three ply face sheets at all load angles. The strength levels and load introduction responses obtained indicated that the 3/16 cell specimens were optimum specimens for developing such data. Two samples from each load angle of this cell size were instrumented with three-arm rectangular strain gage rosettes, one on each face of the specimen on the intersection of the center lines. The specimens were loaded normally except the load was held during strain gage readings. A normal reading of the six arms required approximately one and one-half minutes. During this time the off angle loaded specimens had a tendency to creep at higher load ranges. This reduced the ultimate load capacity of the specimens and lower ultimate stress values were achieved for the strain gaged specimens. The strain gage raw data was input into a computer program written to accept the indicator readings from each arm, sort and collect the arms that belong to each rosette and calculate the principal strains, the angle of principal strain from the axis of the specimen, the Poisson's ratio at the load reading, the stress value, and the secant modulus at the load reading. The computer program is listed in Appendix 3, Section 3, and the reduced data appears in Appendix 2, Section 4. The results appear in Figures 25, 26, 27, 28 and 29. Presented are the axial and transverse stress strain curves of the face sheets for each load angle. The axial strains of the five load angles are compared in Figure 30. The increased stiffness recorded on the

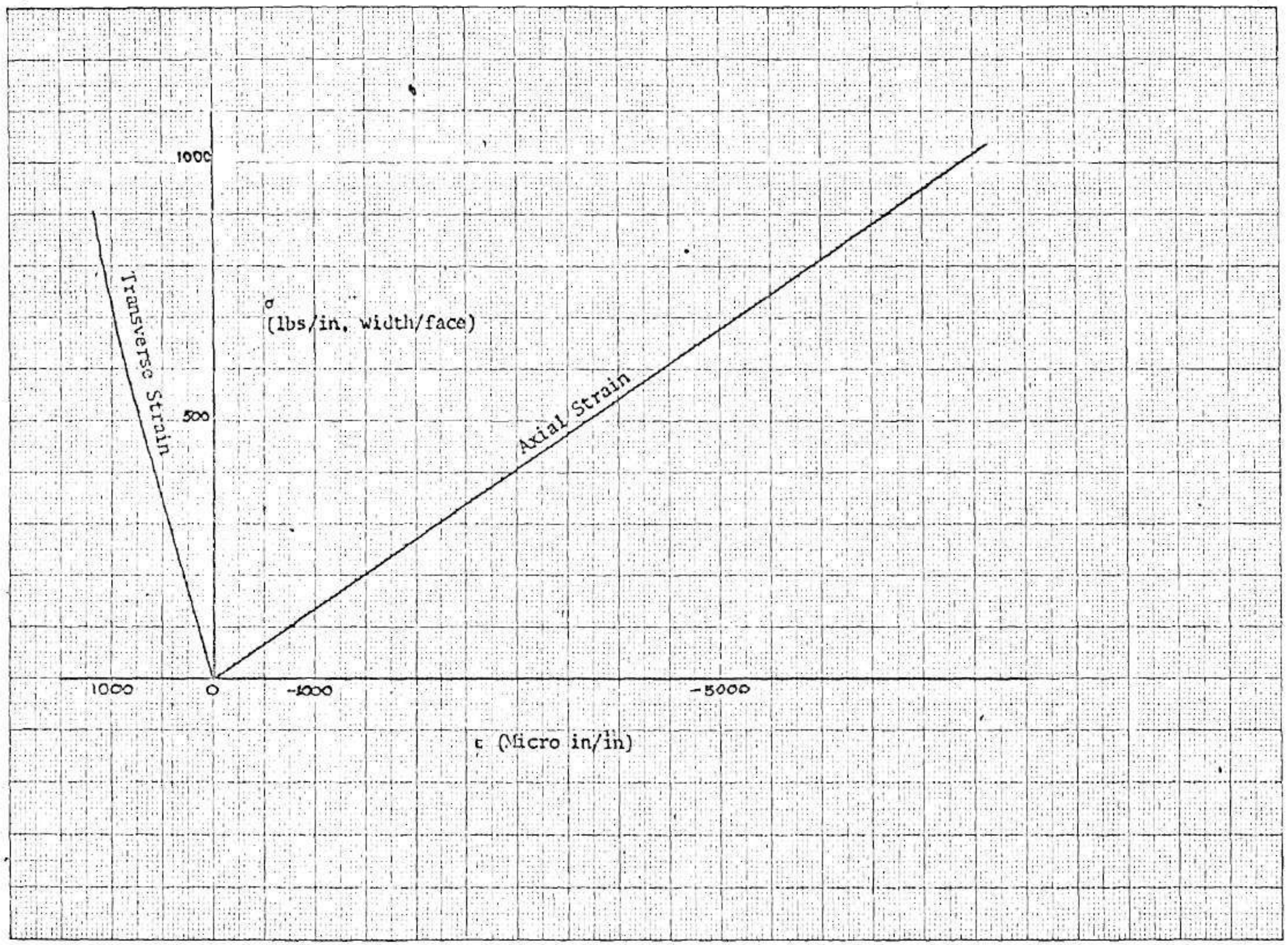


Figure 25. Sandwich Edgewise Compression Stress Strain Response, 0° Oriented, 3/16 Cell

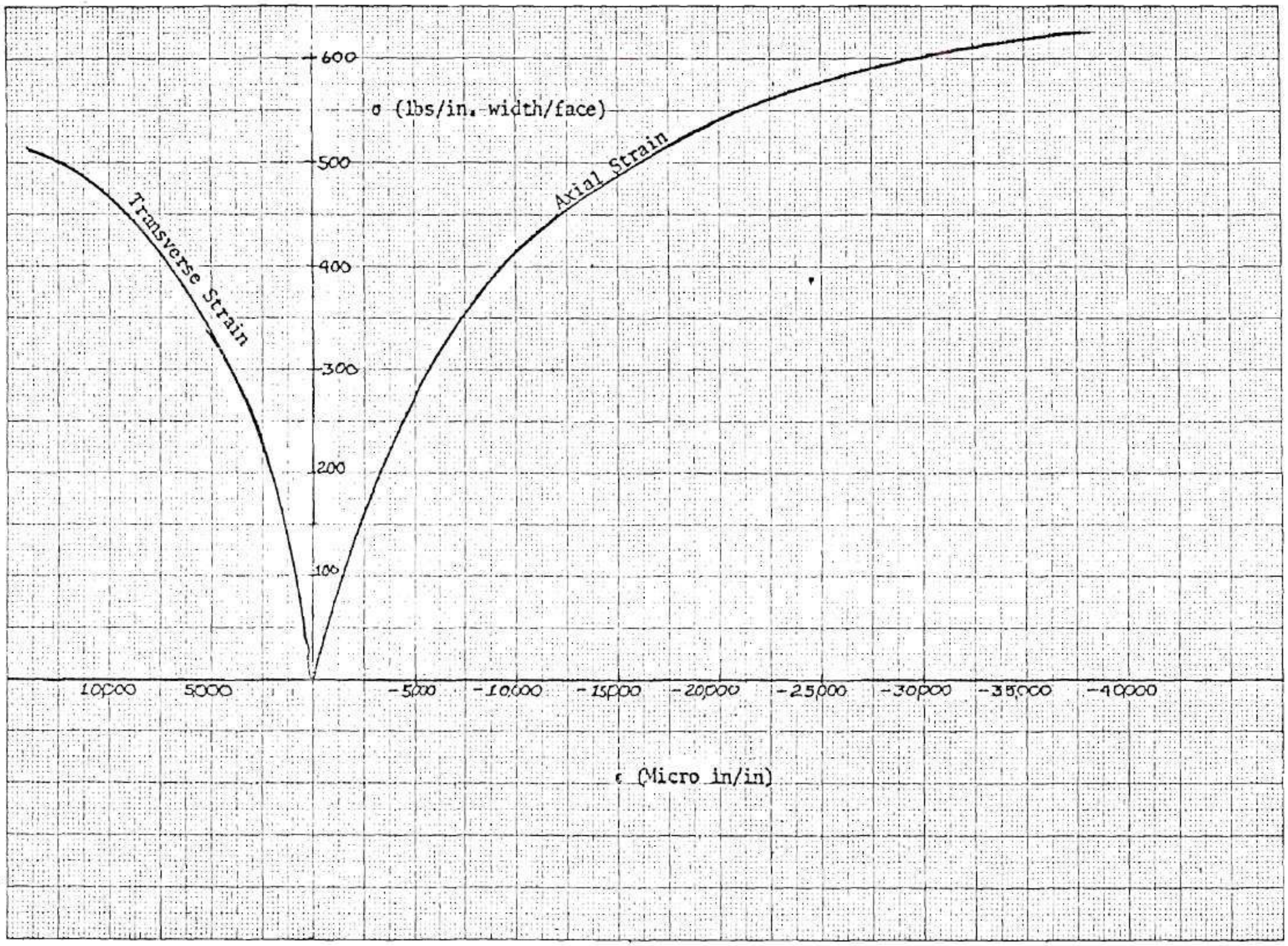


Figure 26. Sandwich Edgewise Compression Stress Strain Response, 30° Oriented, 3/16 Cell

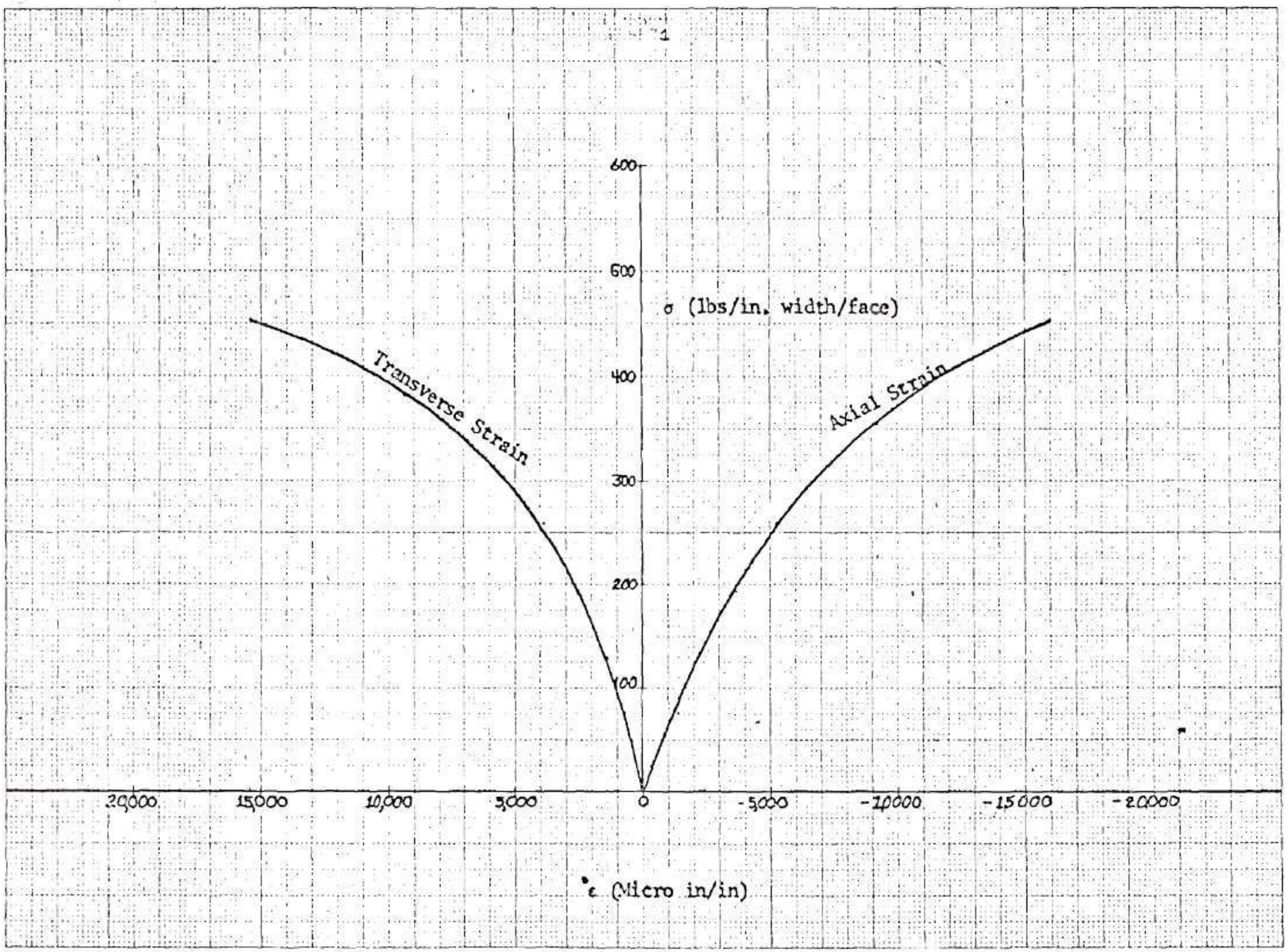


Figure 27. Sandwich Edgewise Compression Stress Strain Response, 45° Oriented, 3/16 Cell

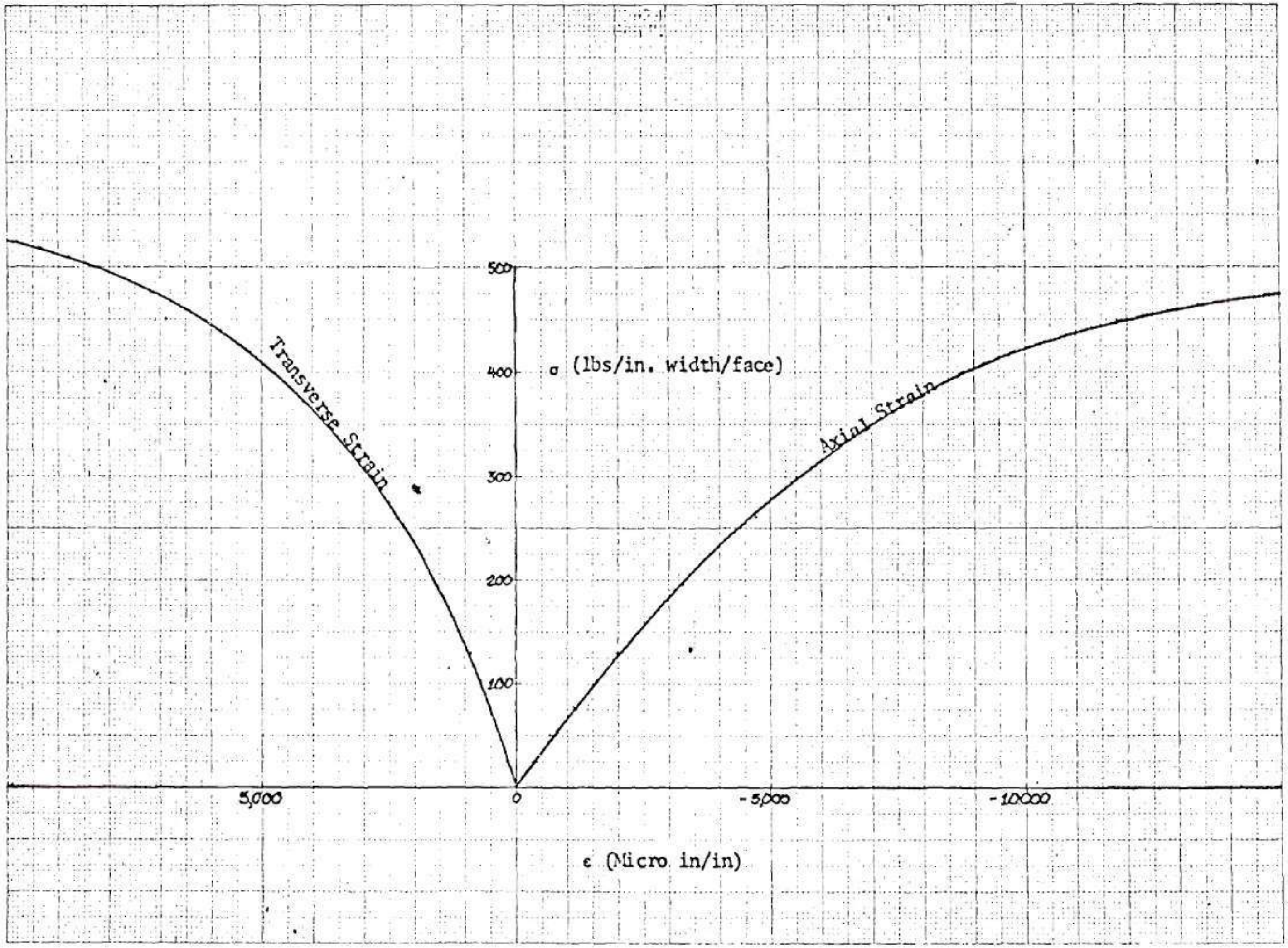


Figure 28. Sandwich Edgewise Compression Stress Strain Response, 60° Oriented, 3/16 Cell

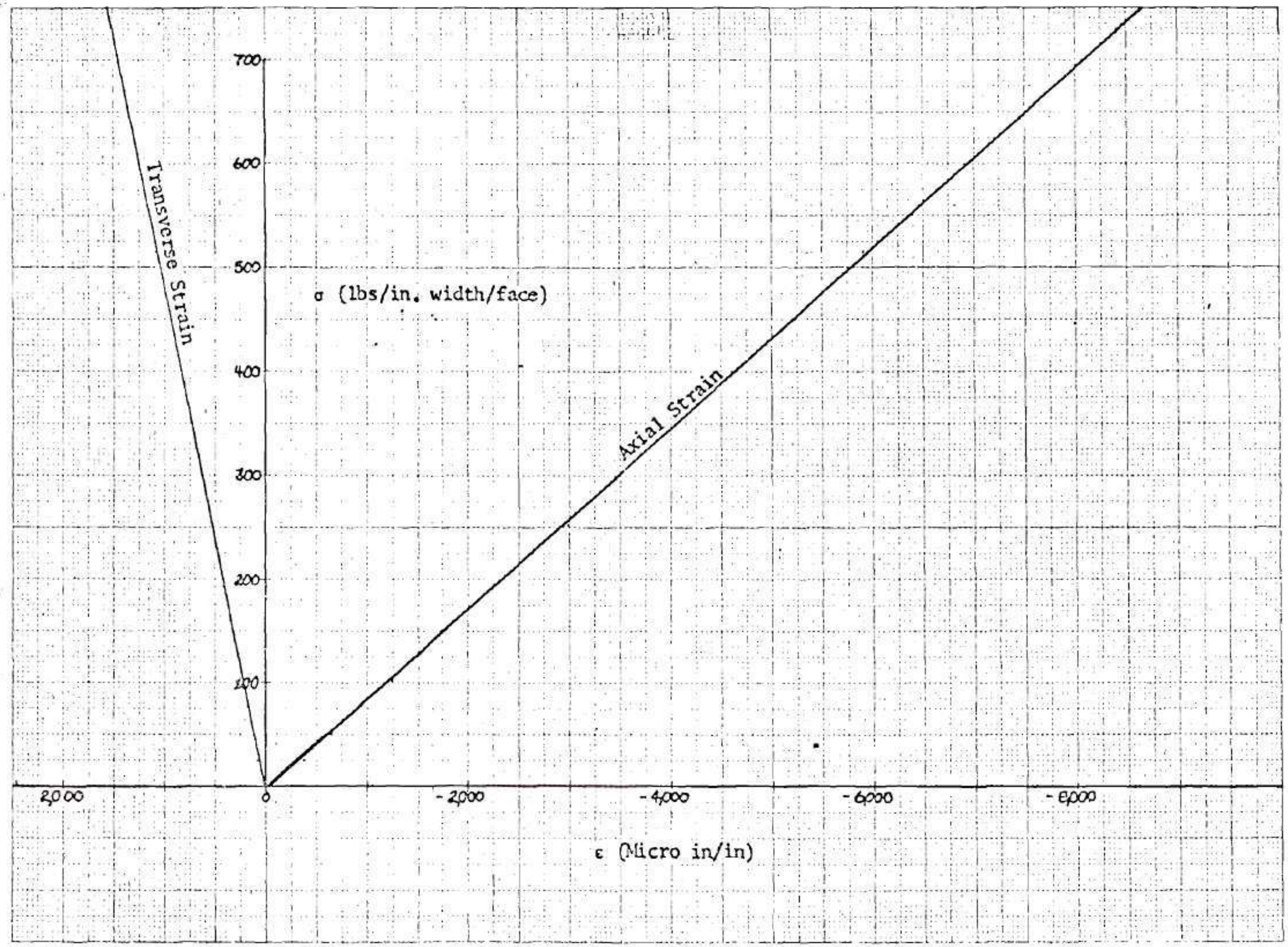


Figure 29. Sandwich Edgewise Compression Stress Strain Response, 90° Oriented, 3/16 Cell

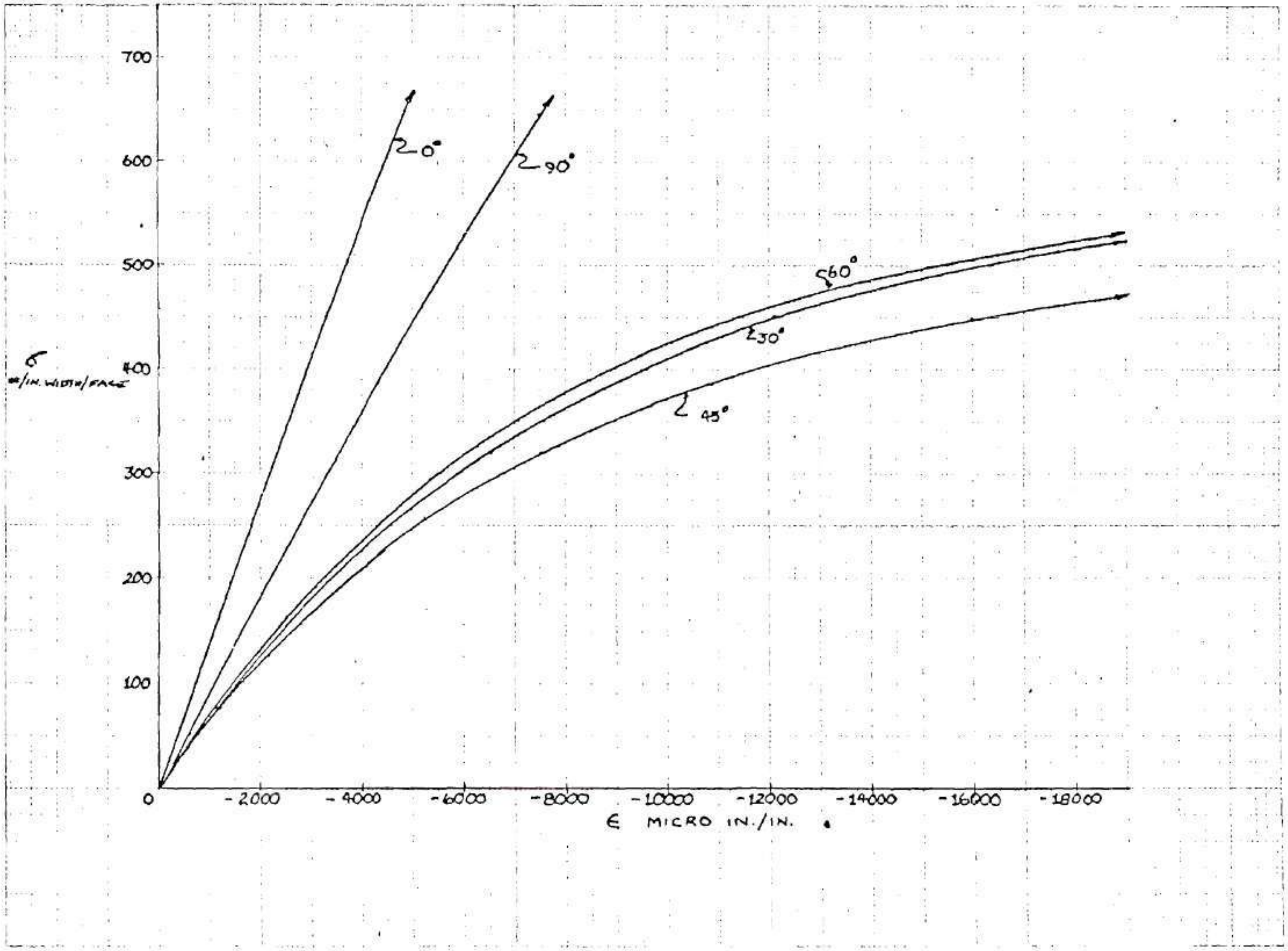


Figure 30. Sandwich Edgewise Compression Axial Stress Strain Response-Comparison of Orientations, 3/16 Cell

edgewise compression tests over those of laminate tests probably resulted from effects of the core.

All the remaining samples were tested for strength properties only. Failure mode was recorded for every test. An improper failure mode, such as end crushing in the clamps, negated the use of that sample in the statistical average.

A statistical sampling was accomplished to attempt to normalize the data for comparative purposes. Some type specimens varied very little in ultimate strength, no matter how they were mishandled, others were extremely sensitive to testing procedure. Also, more specimens were available for certain type tests than for others. In order to compare the data then, a "B" allowable was determined which takes into account sample size and test scatter.

A "B" allowable is defined by Reference 35 as "the mechanical property value . . . above which at least 90 percent of the population of values is expected to fall, with a confidence of 95 percent." Such a value is calculated as follows:

$$\text{"B" allowable value} = \overline{X} - Ks$$

Where $\overline{X}$ is the average ultimate test value; K is one-sided tolerance limit factor for normal distribution for the 95 percent confidence and 90 percent probability level; S is the standard deviation:

$$S = \frac{\Sigma \, (X_i - \overline{X})^2}{n - 1}$$

X_i = individual test value

n = number of test points

The K values were obtained from Reference 36 for values of n from 5 to 50.

The computer program is listed in Appendix 3, Section 4 and the output data in Appendix 2, Section 3.

The strength results for all the load angles and the three core sizes are presented in Table 8. Table 9 compares the optimum sandwich (3/16") compression strength and stiffness for the three ply face sheets to those calculated for three ply laminates from the 12 ply laminate tests. Figure 31 shows the compressive strength and modulus values of the 3/16 cell edgewise compression tests for all load angles. Figures 32 and 33 compare the three ply results presented in Table 9 and calculated using the computer program of Appendix 3, Section 1.

Table 8. Sandwich Edgewise Compression Strength Results

Reduced Test Results	Core Cell Size	Load Angle				
		0°	30°	45°	60°	90°
Average Value (#/in.- width/face)	1/8	955	535	474	504	905 (757*)
	3/16	1230	608	568	601	986
	1/4	1037	589	481	544	982
B Allowance (#/in.-width/face)	1/8	844	501	462	486	747 (691*)
	3/16	919	576	537	526	852
	1/4	934	501	461	506	846
Standard Deviation	1/8	50.5	16.2	5.2	8.6	56.9 (19.2*)
	3/16	112.1	13.7	12.3	31.8	48.1
	1/4	46.7	42.0	8.6	17.9	59.9

*Shear Instability Failure for 1/8 Core

Table 9. Comparison of Three Ply Compression Properties from Laminate and Sandwich Tests

Load Angle	Compression Properties			
	3 Ply Reductions of 12 Ply Laminate Tests (#/in.-width/3 Ply Laminate)		3 Ply Face Sheets of 3/16 Core Edgewise Compression (#/in.-width/3 Ply Face)	
	Strength	Modulus	Strength	Modulus
0°	1730	101,000	1230	135,000
30°	660	66,000	608	71,000
45°	580	59,000	568	62,000
60°	650	64,000	601	67,000
90°	1360	94,000	986	85,000

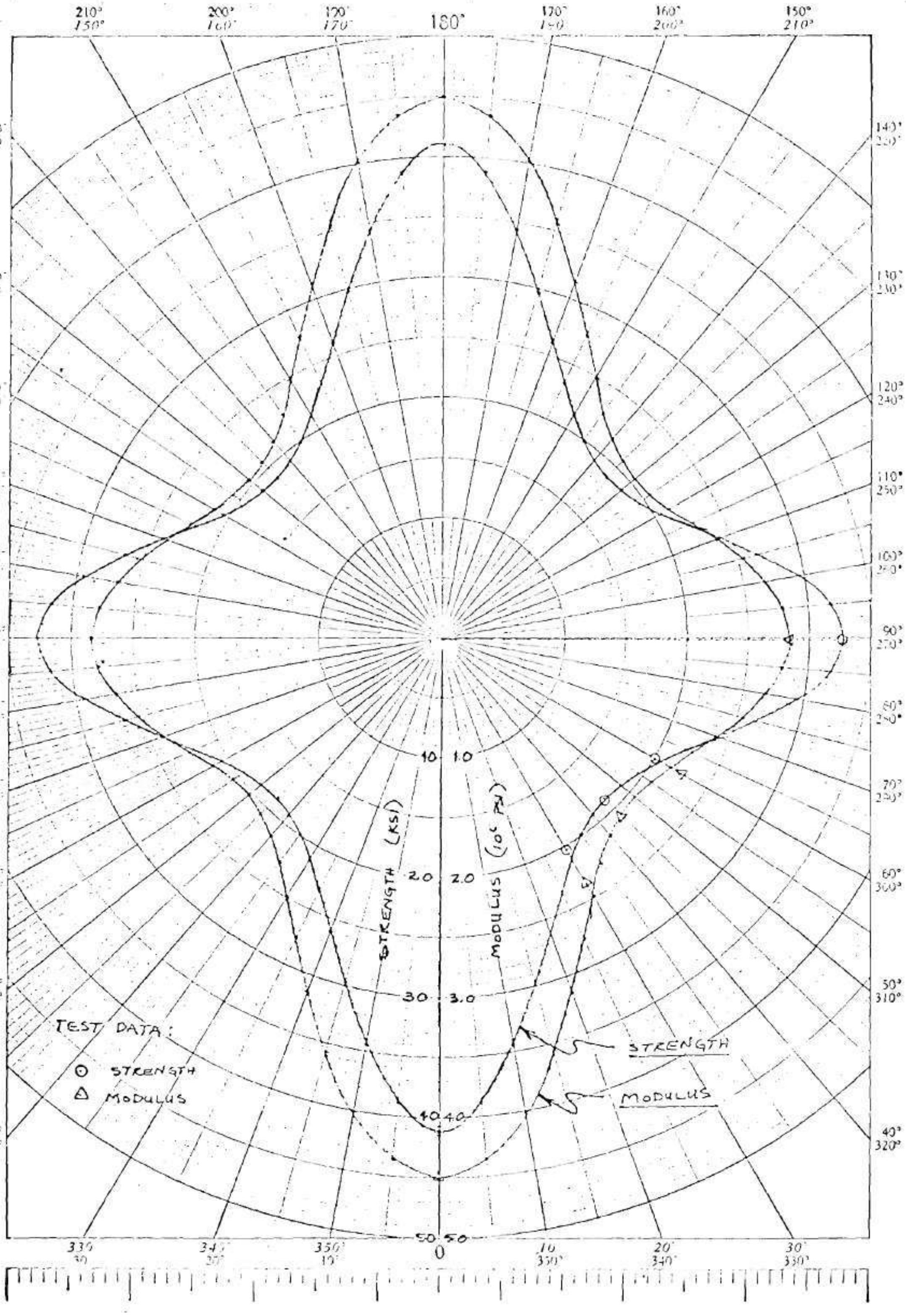


Figure 31. Edgewise Compression Results (3/16 Cell Size)

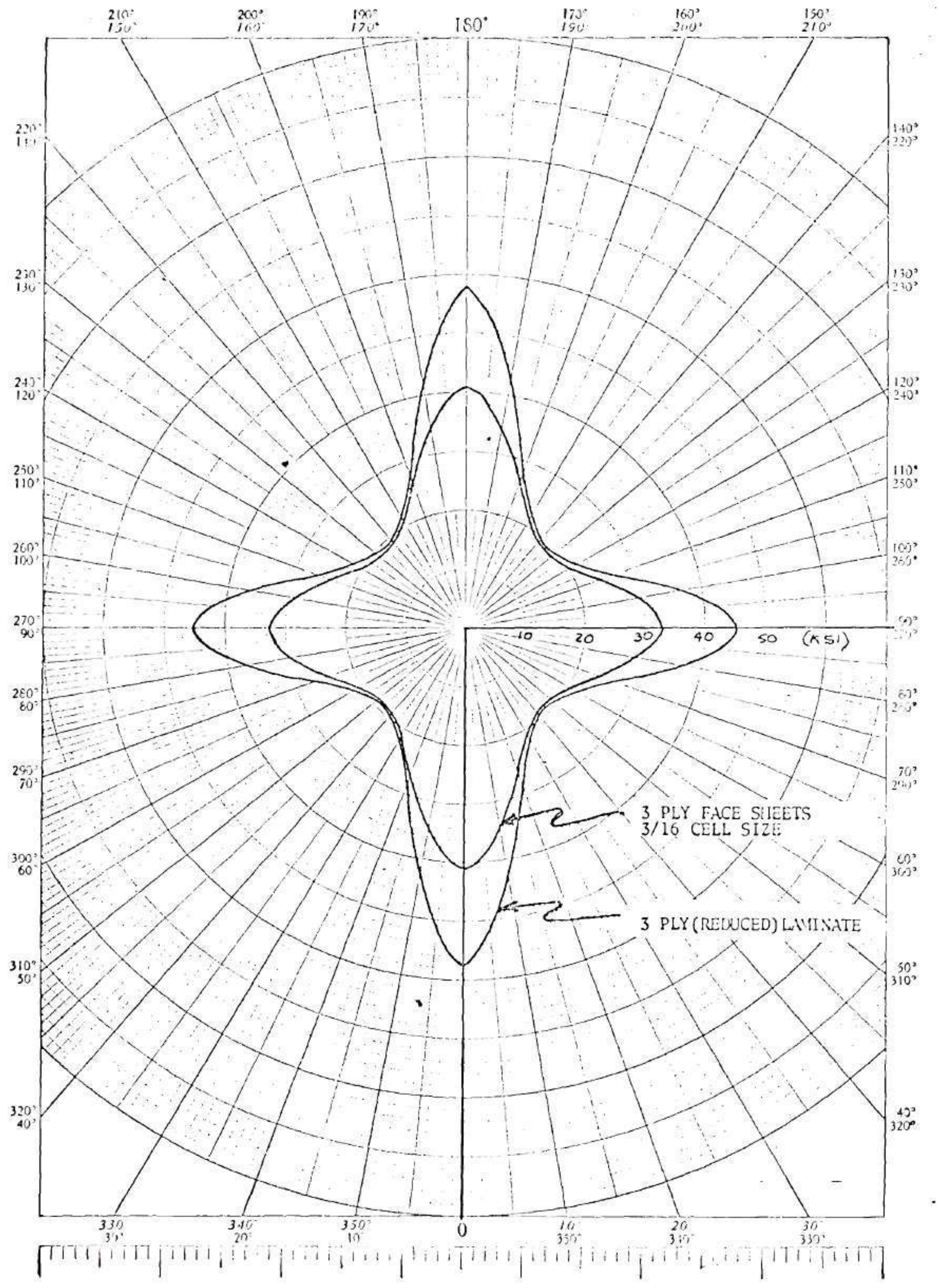


Figure 32. Comparison of 3 Ply Strength Results

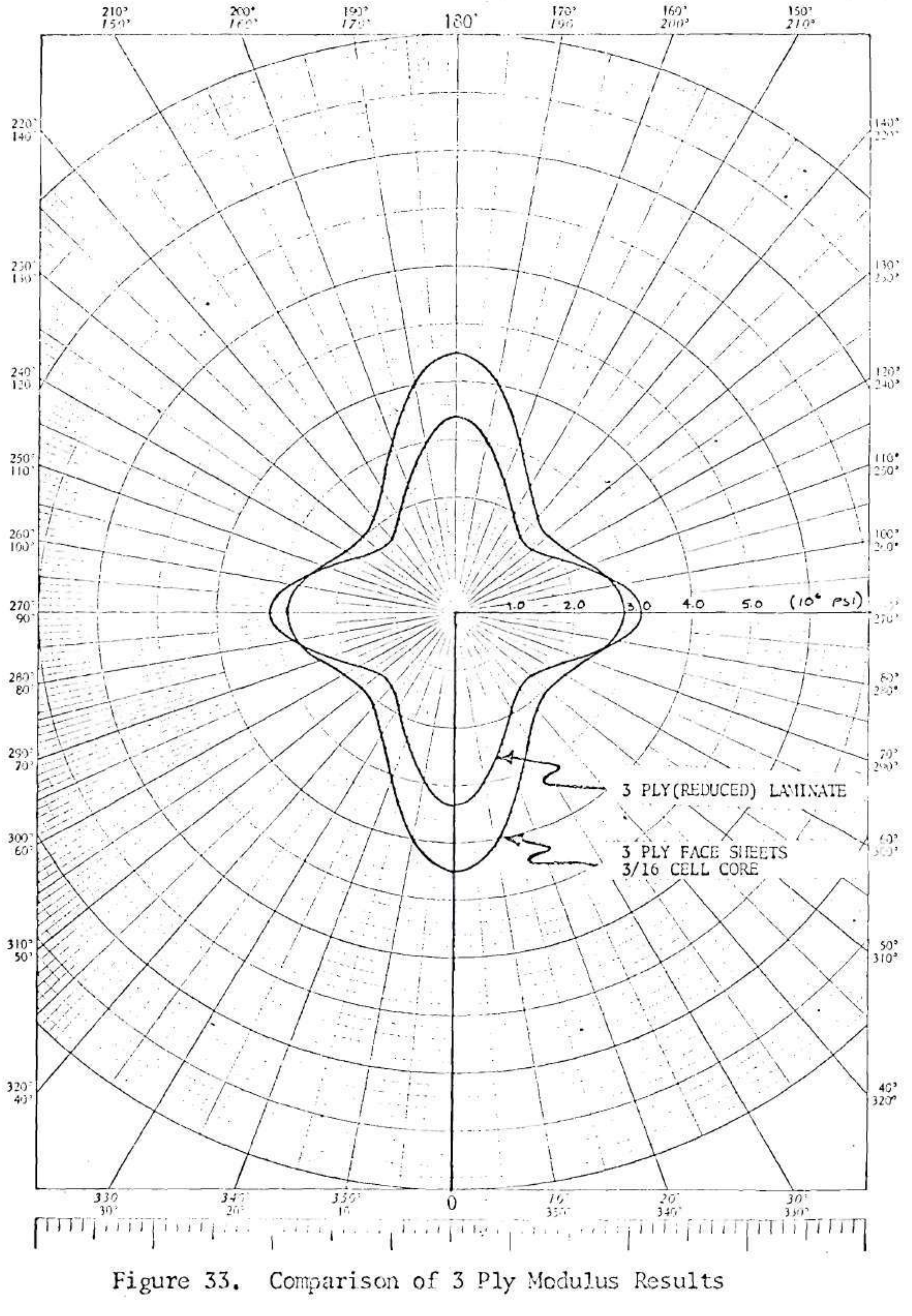


Figure 33. Comparison of 3 Ply Modulus Results

CHAPTER V

CONCLUSIONS

An orderly plan of study was conducted to investigate the response of orthotropic, fiberglass-faced, honeycomb core, sandwich structure loaded at various angles to the material axes of typical short column, lightweight, aircraft type, edgewise compression test specimens.

The mechanical properties of the fiberglass reinforced plastic laminate face sheet material (epoxy adhesive prepreg) have been determined and reduced to equivalent face sheet type thin gage material properties. The test laminates were of high overall quality. The laminate test results indicate the adhesive prepregs have lower mechanical properties than those of conventional high strength epoxy/fiberglass laminates.

The adhesive prepreg one step bonding fabrication technique yields high quality bonded sandwich panels as determined by the flatwise tensile test results. The flexural shear tests verify this conclusion by providing a face sheet failure rather than an adhesive shear failure when performed on panels constructed of high shear strength core.

Edgewise compression tests were performed on specimens of three core sizes (1/8, 3/16 and 1/4 inch) at five load angles 0°, 30°, 45°, 60° and 90°). Although expected, face wrinkling and face dimpling (intracellular buckling) failure modes did not appear during edgewise compression tests. Although not expected, shear crimping did occur on some of the 90° load angle, 1/8 inch cell size tests. Face sheet compressive strength failure occurred on all of the remainder of the edgewise compression tests, including the remaining 90° load angle, 1/8 inch cell size specimens.

A photoelastic investigation indicated that for certain specimens, face wrinkling was incipient as was face dimpling of other selected specimens. This investigation also demonstrated the importance of aligning an edgewise compression specimen with a spherical seat normal to the loading to prevent uneven load distribution.

Strain gage instrumented specimens provided face sheet modulus and Poisson's ratio values. The modulus values were higher than expected for the face sheet material and probably represent a stiffening effect of the core.

Strength tests indicate the 3/16 inch core as the optimum size core to distribute the load evenly yet not influence the face sheet response. The shape of the curves presented in the polar coordinate graphs show that if the load angle is off two or three degrees near the zero or ninety axes, significant strength or modulus reductions occur. Therefore, small errors are amplified when testing in this region. Test scatter was extremely high for all 0° and 90° specimens, indicating the sensitivity of the specimens to test technique. Test scatter was relatively low for the 30°, 45° and 60° specimens, indicating these specimens were very forgiving. The most difficult test to perform was the 90° tests. The specimens failed quite often at the clamps. The core is so flexible in a 90° orientation that the potting compound acted like the tangs of a tensile specimen and stiffened the face sheets too abruptly, causing a stress concentration and failure at the edge of the core/potting compound interface.

Inspection of some of the end crushing failures show that it is important to square off the face sheets and extend them all the way to the loading block. Any loading transferred from only potting compound to the face sheets resulted in end failures within the end clamps.

The edgewise compression test provides an excellent means to test off angle, thin gage, fiberglass-reinforced plastic laminates for strength values. The same test may be used for 0° and 90° orientations; however, extreme care must be taken in test procedures. Modulus values, if obtained, would have to be reduced to delete the effect of the core. This reduction would be a function of the core density and most likely would have to be experimentally determined.

CHAPTER VI

RECOMMENDATIONS

Applications

The edgewise compression test should be used in conjunction with a spherical seating apparatus to provide a means to test thin gage fiberglass-reinforced plastic laminates at all load angles for ultimate strength values. A 3/16 inch cell size core should be used.

Adhesive prepregs produce a high quality, tough, lightweight, aircraft type sandwich structure and should be considered for general service in the airframe industry.

Further Studies

Tests on thin gage laminates are needed to compare the theoretically developed reductions of strength and stiffness due to reductions in laminate thickness.

Accurate determinations of Poisson's ratios at various load angles on fiberglass laminates are needed.

Means for measuring the initial waviness of the interior surface of the face sheets of single stage layup fiberglass-faced sandwich structure should be developed. With the more accurate measurements, the face wrinkling analysis should be reinvestigated and more extensive tests conducted to substantiate such analysis. Specimens should be redesigned to preclude strength failure and promote face wrinkling.

The intracellular analysis should be placed on a firmer theoretical basis and confirmed with tests on larger core sizes and thinner face sheets.

Development and extension of the photoelastic technique should be pursued. This technique can be a powerful tool as a quality control device, qualitative analysis aid, and quantitative measuring instrument.

The shear crimping analysis [9] should be discarded for this case, and a realistic rationale substituted. The assumption in [14] that [9] presents an acceptable means for predicting shear crimping failure for FRP faced sandwich structure should be examined in more detail. Additional tests should be conducted to verify the existence of such failure as discovered in this series of tests.

Improved end clamps along the lines of the ASTM slotted rods should be thoroughly investigated to possibly preclude the end clamp failures obtained here. Means such as the FPL Marten's mirror compressometers should also be investigated to provide an easy method to verify the even loading of the two face sheets of the edgewise compression specimens.

APPENDIX I

QUALITY CONTROL DATA

Section 1: Panel Process Data

The following "part riders" accompanied each sandwich panel through the processing operations at the manufacturer, American Cyanamid Company, Bloomingdale Department, Havre de Grace, Maryland. Each "rider" lists the panel by an identification number. The following list identifies the panel and describes which tests were performed using that panel.

Panel Number	Core Cell Size	Type Test	Load Angle
BP 919-158-2	1/8	Edgewise Compression	0°
BP 919-158-5	1/4	Edgewise Compression	30°
BP 919-148-6	1/4	Flatwise Compression, Flatwise Tension, Flexural Shear	
BP 919-158-7	1/4	Edgewise Compression	90°
BP 919-158-9	1/4	Edgewise Compression	45°
BP 919-158-12	1/4	Edgewise Compression	60°
BP 919-158-13	1/4	Edgewise Compression	0°
BP 919-158-15	1/8	Edgewise Compression	90°
BP 919-158-16	1/8	Flatwise Compression, Flatwise Tension, Flexural Shear	
BP 919-158-17	1/8	Edgewise Compression	45°
BP 919-158-18	1/8	Edgewise Compression	60°
BP 919-158-20	1/8	Edgewise Compression	30°
BP 919-113-3	3/16	Edgewise Compression	45°
BP 919-113-4	3/16	Edgewise Compression	60°
BP 919-113-7	3/16	Edgewise Compression	30°
BP 919-113-8	3/16	Edgewise Compression	90°
BP 919-113-9	3/16	Edgewise Compression	0°
BP 919-113-10	3/16	Flatwise Compression, Flatwise Tension, Flexural Shear	

PROJECT NO. 9JJJ

SANDWICH DATA SHEET.

TO ______ FROM ______ DATE OCT 30, 67

Purpose for making the panel STM 22 — 506

Please laminate the following ~~[illegible]~~ panels and report TYPE AC

the results to: ______

MATERIAL: BP - 919 - 158

TOOL COVER	CORE CLEANING PROCESS
MYLAR	
RELEASE FILM TEFLON	VAPOR DEGREASE: X
	OTHER:
	CORE DRYING PROCESS
3-PLIES PREPREG	20 MIN @ 130 °F
CORE 1/8 .0009 5052 N .50" THICK.	
3-PLIES PREPREG	SIZE 19 X 20" WARP 20"
	CORE RIBBON DIRECTION 20"
	"-FILL" FACE SIDE AGAINST CORE
RELEASE FILM TEFLON	
BOTTOM CAUL PLATE .250"	

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP - 919 - 158 - Z

Made By C. Th[illegible] On 30 Oct 1967

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95TJ

BATCH NO:

CURING CYCLE DATA

CUSTOMER STM 12-506

LAMINATE NO: BP919-158-2

DATE 30 OCT 67

SIZE: 19"x20"

NO. PLIES: 3 TOP - 3 BOT + CORE 1/8" .0009" 5052 .50" THICK

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☐

CYCLE INSTRUCTIONS: RT — 250°F IN 50 MIN.

60' MIN HOLD AT 250 °F 25 PSI AIR.

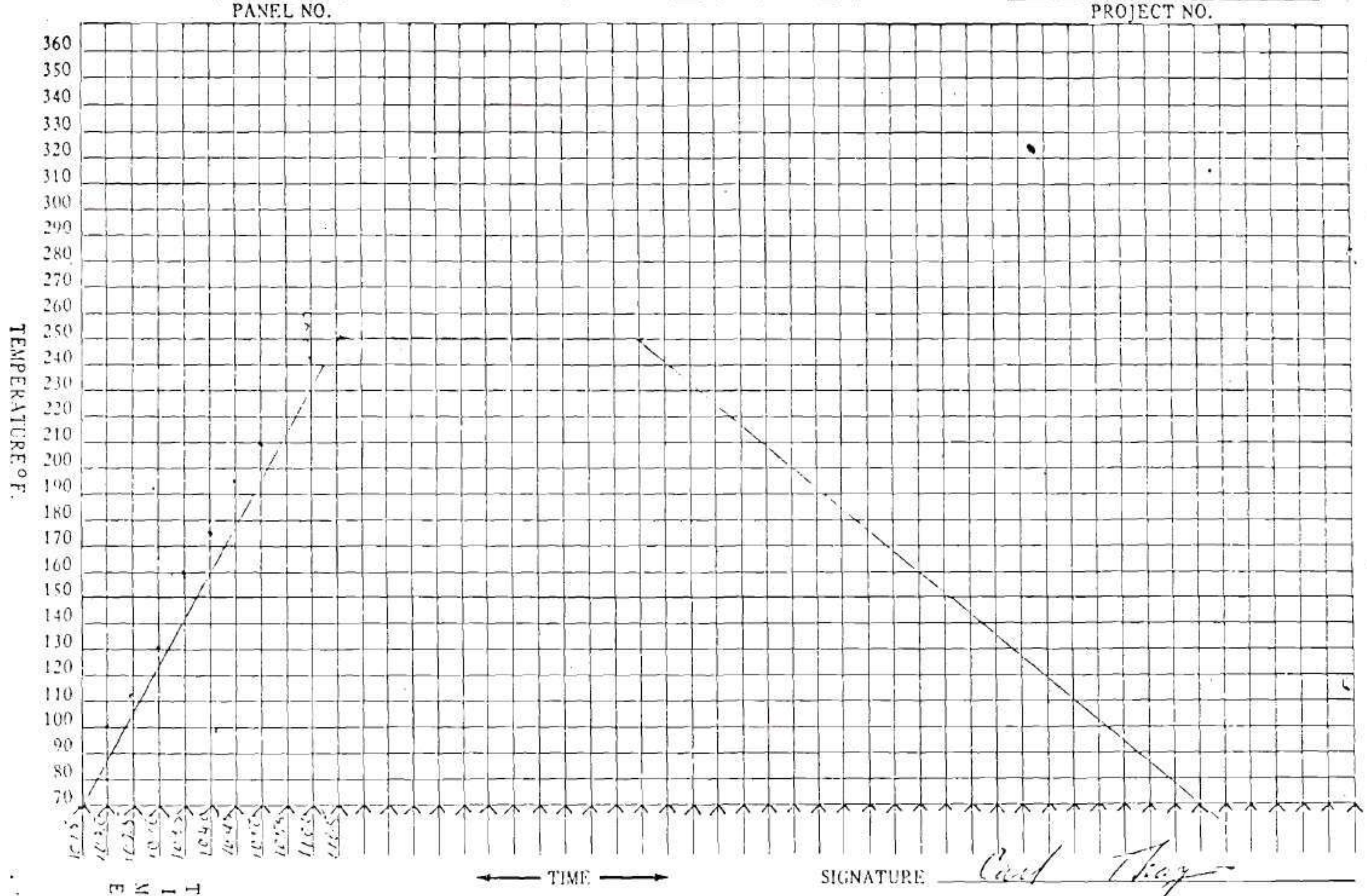
Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
1015	70				400	VENT	ON - OFF	25 PSI	START
1020	100				400	TO	ON - OFF	25 PSI	
1025	112				400	ATMOS		25 PSI	
1030	130				400			25 PSI	
1035	160				400			25 PSI	
1040	175				400			25 PSI	
1045	190				400			25 PSI	
1050	210				400		12	25 PSI	
1055	222				400		19	25 PSI	
1100	242				400		20	25 PSI	
1105	251				400		20	25 PSI	
									HOLD
1205				HOLD 60' MIN @ 250 °F					COOL

MG-63L REV. 6/24/64

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

BP919 -158-2
PANEL NO.

95JJ
PROJECT NO.



SIGNATURE Carl Thag

DATE 30 Oct, 1967

PROJECT NO. ____

SANDWICH DATA SHEET.

TO ____ FROM ____ DATE Nov. 6, 67

Purpose for making the panel STM 22 — 506

Please laminate the following ~~sandwich~~ panels and report OK, TYPE AC

the results to: ____

MATERIAL: BP-919-158

TOOL COVER	CORE CLEANING PROCESS
MYLAR	
RELEASE FILM TEFLON	VAPOR DEGREASE: X
	OTHER:
	CORE DRYING PROCESS
3-PLIES PREPREG	20 MIN @ 130 °F
CORE [1/4", .004" 5052 N.50 "T"]	
3-PLIES PREPREG	SIZE 19 x 20" WARP 20
	CORE RIBBON DIRECTION 20"
	"FILL" FACE SIDE AGAINST CORE
RELEASE FILM TEFLON	
BOTTOM CAUL PLATE .250"	

Pressure: -Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ____

REMARKS: ____

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-158-5

Made By C.K.T. On 11-6-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95JJ

BATCH NO:

CURING CYCLE DATA

CUSTOMER [illegible]

LAMINATE NO: 919-2155-5

DATE 6 DEC 67

SIZE: 19 X 20

NO. PLIES: CORE.

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☒

CYCLE INSTRUCTIONS:

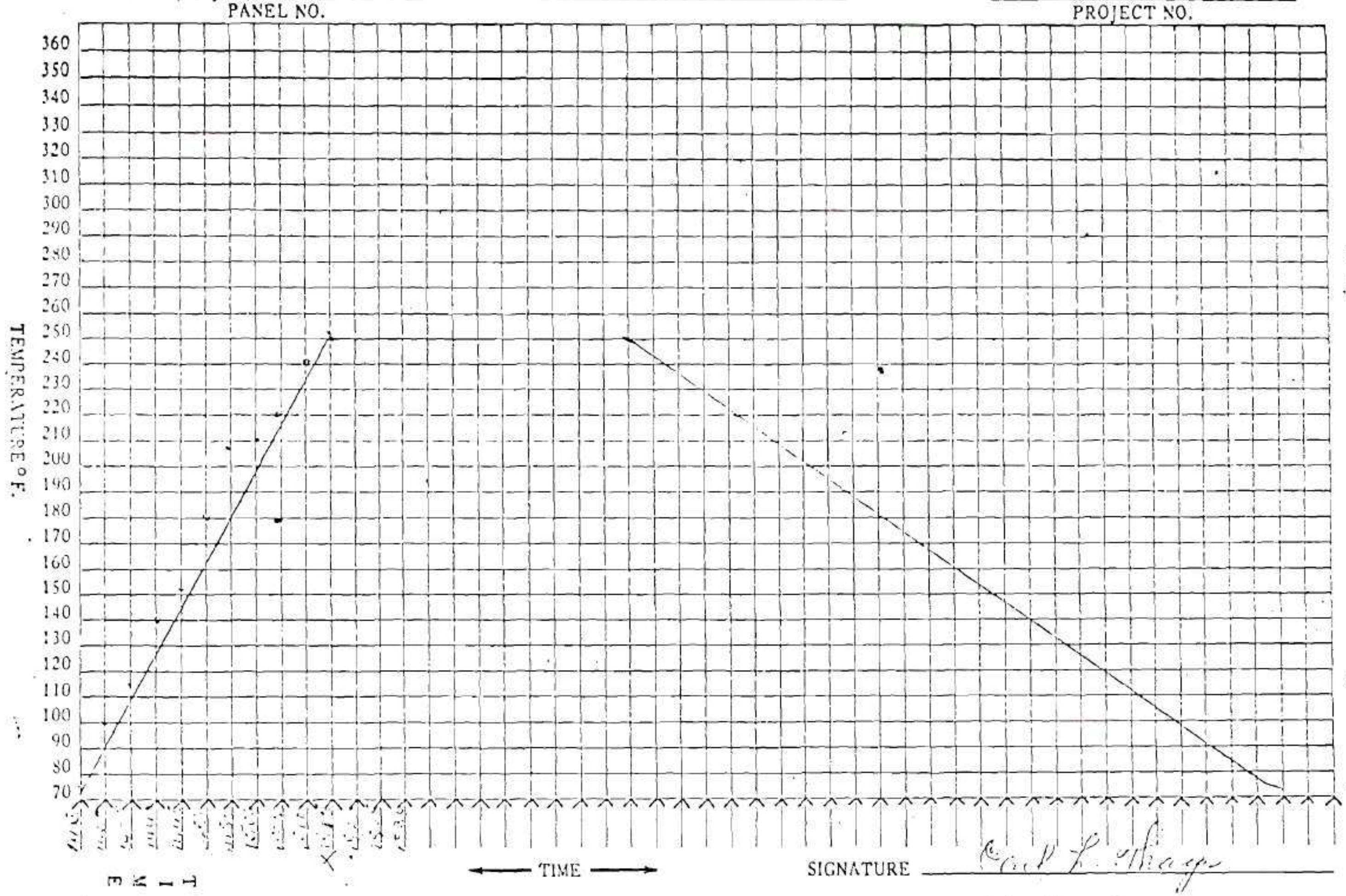
RT-250°F [illegible] ; 60' [illegible] @ 250°F 25 PSI AIR

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
1425	71								START
1430	100								
1435	115								
1440	140								
1445	152								
1450	180								
1455	209								
1500	210								
1505	~~240~~								
1510	240								
1515	251	—	HOLD		1 HOUR @		250°F		
1520									
1615	—	—	—	—	—	—	—	—	Turn off Steam

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

919-158-5
PANEL NO.

95TT
PROJECT NO.



SIGNATURE [signature]

DATE 11-6-67

SANDWICH DATA SHEET

TO ______ FROM ______ DATE ______

Purpose for making the panel STM 22 — 506

Please laminate the following panels and report OK, TYPE AC

the results to: ______

MATERIAL: BP-919-158

TOOL COVER
MYLAR
RELEASE FILM TEFLON

3-PLIES PREPREG
CORE 1/4" .004" 5052 N .50" THICK
3-PLIES PREPREG

RELEASE FILM TEFLON
BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS
VAPOR DEGREASE: X
OTHER:

CORE DRYING PROCESS
20 MIN @ 130 °F

SIZE 19" X 20" WARP 20
CORE RIBBON DIRECTION 20"
"FILL" FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-158-6

Made By Carl L. Thorp On 11-3-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 9.5TJ

BATCH NO:

CURING CYCLE DATA

CUSTOMER [illegible] 72-50L.

LAMINATE NO: CP-919-158-G

DATE 11 FEB-67

SIZE: 19"x20" 20 WARP

NO. PLIES: 3 TOP- 3-BOT.

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☐

CYCLE INSTRUCTIONS:

RT-250°F IN 50', 60 MIN @ 250°F 25 PSI AIR

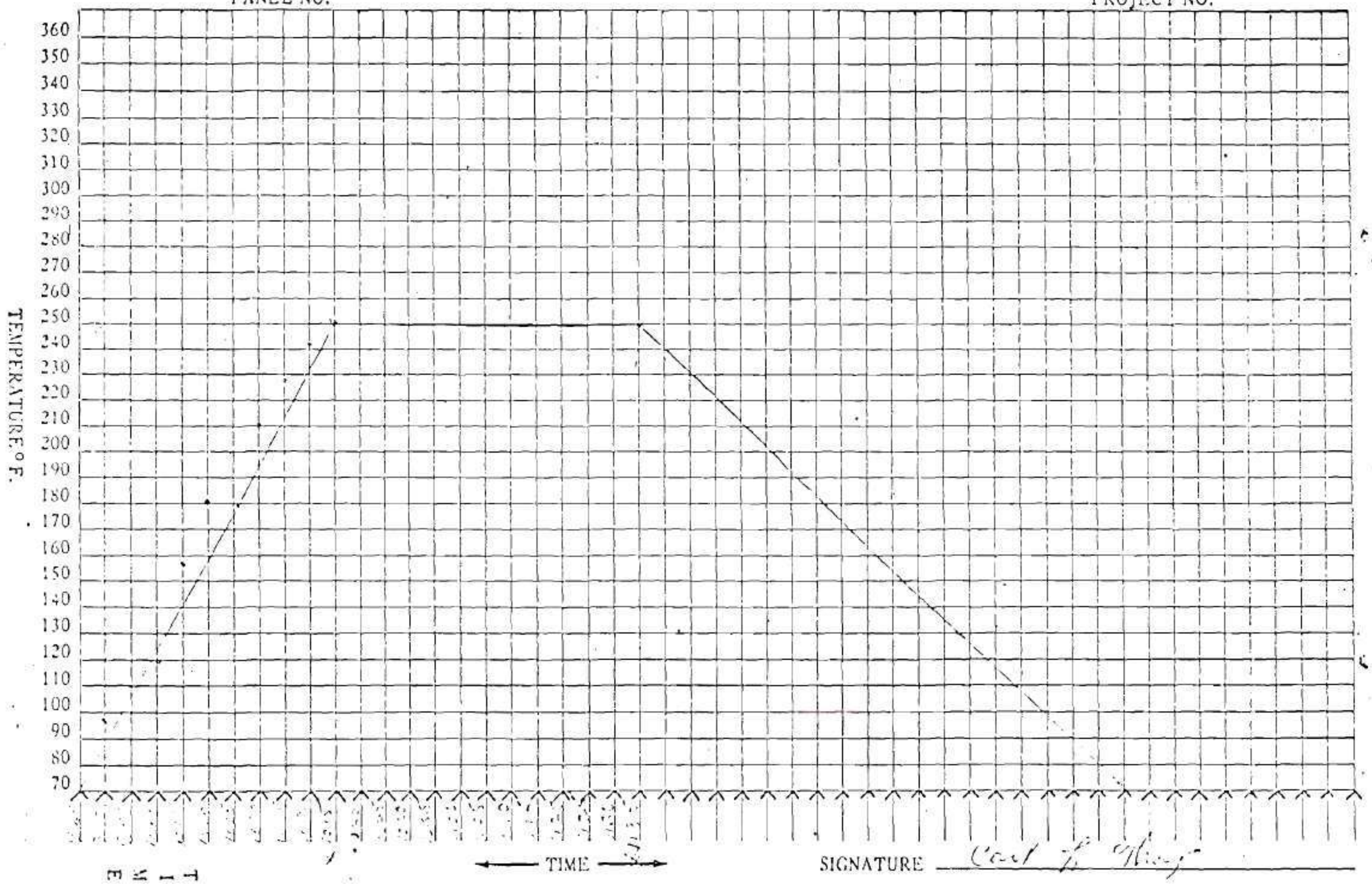
Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
9.45	70				400	VENT		25 PSI.	START
950	97				"	TO		"	
955	110				"	ATMO.			
1000	120				"				
1005	157				"	"		"	
1010	183				"				
1015	200				"	"			
1020	211				"			"	
1025	227				"				
1030	242				"	"		"	
1035	25?	—	—	—	HOLD	60 MIN @ 250 °F		"	HOLD
1040									
1045					"	"			
					"	"			
						"		25 PSI AIR	
1115	253								
1135	254				400	"		25	COOL 1135

NG-63L REV. 6/24/64

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PANEL NO.: 95JJ

PROJECT NO.: CP 919-158-6



SIGNATURE [illegible]

DATE 11-8-67

PROJECT NO. ______

SANDWICH DATA SHEET.

TO ______ FROM ______ DATE 9 NOV 67

Purpose for making the panel STM 22 - 506

Please laminate the following sandwich panels and report the results to: ______ TYPE A.C.

MATERIAL: BP-919-158

OK

TOOL COVER
MYLAR
RELEASE FILM TEFLON

3-PLIES PREPREG
CORE 1/4" .004" 5052 N .50" THICK
3-PLIES PREPREG

RELEASE FILM TEFLON
BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS
VAPOR DEGREASE: X
OTHER: ______

CORE DRYING PROCESS
20 MIN @ 130 °F

SIZE ______ WARP
CORE RIBBON DIRECTION ______
"-FILL" FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-915-158-1

Made By [illegible] On 11-9-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95-JJ

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: EP 919-153-7

DATE 11-9-67

SIZE: 19" x 20" ↑

NO. PLIES: 3 Top — 3 Bottom

TYPE: AC

VAC. ☐ PRESS ☐ AUTOCLAVE ☒

CYCLE INSTRUCTIONS: R.T. → 250°F in 30 min. 60 min hold @ 250°F 2 Hrs. To Cool To 150°F. End of Cool Down

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
855	R.T.				40z	Vent to Atmos.	on/off	35 psi	START
9:00	97°				40z	"	on/off	35 psi	HEAT UP CYCLE
9:05	115°				40z	"	on/off	35 psi	
9:10	133°				40z	"	on/off	35 psi	
9:15	151°				40z	"	on/off	35 psi	
9:20	169°				40z	"	on/off	35 psi	
9:25	189°				40z	"	on/off	35 psi	
9:30	209°				40z	"	on	35 psi	
9.35	224°				40z	"	on	35 psi	
9.40	239°				40z	"	on	35 psi	
9:45	245°				40z	"	on	35 psi	
9.45	250°				40z	Vent To Atmos.	On Regulator	35 psi	60 Min Hold @ 250°F
10:45	off	Start	Cool	Down	40z	Vent To Atmos	Off	35 psi	2 Hrs. To Cool To 150°F.

NG-63L REV. 6/24/64

Dennis

AMERICAN C NAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

BP-919-158-7
PANEL NO.

Auto Clave Panel

95-JJ
PROJECT NO.

SIGNATURE

DATE 11-9-67

PROJECT NO. 95JJ

SANDWICH DATA SHEET.

TO ______ FROM ______ DATE 15 Nov 67

Purpose for making the panel STM 22—506

Please laminate the following sandwich panels and report TYPE A.C.

the results to:

MATERIAL: BP- 919-158

TOOL COVER	CORE CLEANING PROCESS
MYLAR	
RELEASE FILM TEFLON	VAPOR DEGREASE: X
	OTHER:
	CORE DRYING PROCESS
3-PLIES PREPREG	20 MIN. @ 130 °F
CORE [1/4" .004" 5052 N .50" THICK]	
3-PLIES PREPREG	SIZE 19 x 20" WARP
	CORE RIBBON DIRECTION
	"-FILL" FACE SIDE AGAINST CORE
RELEASE FILM TEFLON	
BOTTOM CAUL PLATE .250"	

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.)

REMARKS:

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-158-9

M.d. by Phil Witt On 11-15-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95-77

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: BP-919-458-9

DATE

SIZE:

NO. PLIES: 3 EACH SIDE

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☒

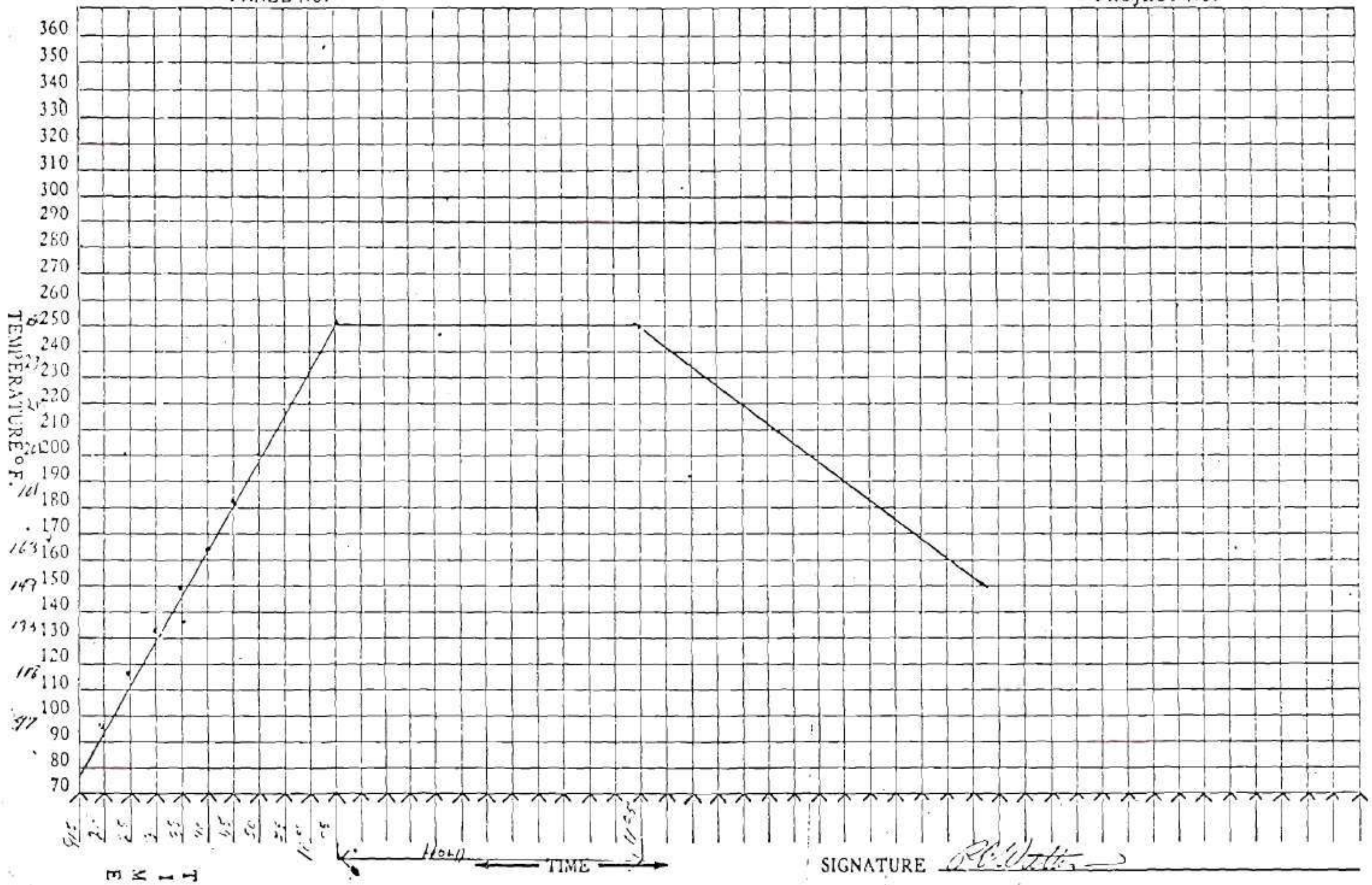
CYCLE INSTRUCTIONS:

	Temp. Stations								
Time	1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
9:15			85			VENT		25 PSI	
20			97					"	
25			116					"	
9:30			133					25 PSI	
35			149					"	
40			163					"	
45			181					25 PSI	
50			201					"	
55			218					"	
10:00			232					25 PSI	
10:35 05			250					25	
HOLD CONSTANT @ 250 °F						VENT		25 PSI	
11:05	Cool	under			pressure	Air		25 PSI	

PRWatson

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

BP-919-158-9 | [illegible] | 95-52
PANEL NO. | | PROJECT NO.



SIGNATURE [illegible]

DATE 11-15-67

SANDWICH DATA SHEET.

FROM ____ DATE 8 17 ... 67

se for making the panel STM 22 — 506

Please laminate the following ~~cutthrough~~ panels and report the results to: ____

TYPE A.C.

MATERIAL: BP - 919 - 158

TOOL COVER	CORE CLEANING PROCESS
MYLAR	
RELEASE FILM TEFLON	VAPOR DEGREASE: X
	OTHER:
	CORE DRYING PROCESS
3-PLIES PREPREG	20 MIN @ 130 °F
CORE 1/4" .004" 5052 N .50" THICK	
3-PLIES PREPREG	SIZE 19 X 19 WARP 19"
	CORE RIBBON DIRECTION 90°
	"-FILL" FACE SIDE AGAINST COR
RELEASE FILM TEFLON	
BOTTOM CAUL PLATE .250"	

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ____

REMARKS: ____

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP - 919 - 158 - 12

Made By [illegible] On [illegible]

3rd cycle

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. [illegible]

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: [illegible]

DATE

SIZE: [illegible]

NO. PLIES: [illegible]

TYPE: [illegible]

VAC. ☐ PRESS ☐ AUTOCLAVE ☐

CYCLE INSTRUCTIONS: [illegible]

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible] cycle
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

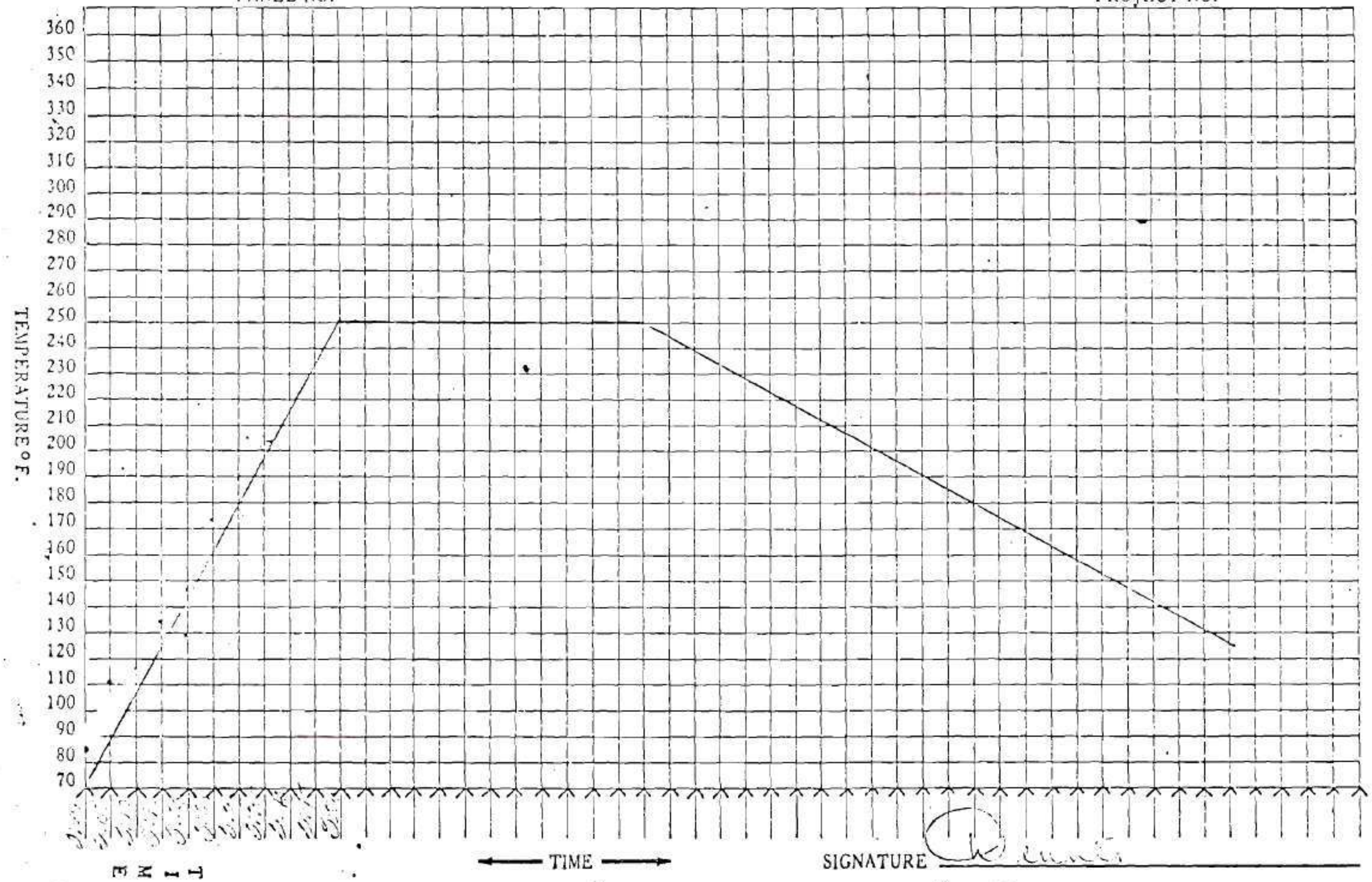
HG-63L REV. 6/24/64

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PD-917-158-12
PANEL NO.

AC Panel

PROJECT NO.



SIGNATURE

DATE 11-17-67

PROJECT NO. ______

SANDWICH DATA SHEET.

TO. ______ FROM ______ DATE 21 NOV 67

Purpose for making the panel: STM 22 — 506

Please laminate the following adhesive panels and report the results to: ______

TYPE A.C.

MATERIAL: R.P. 919-158-

TOOL COVER
MYLAR
RELEASE FILM TEFLON

3-PLIES PREPREG
CORE [1/4" .004" 5052 N .50" THICK]
3-PLIES PREPREG

RELEASE FILM TEFLON
BOTTOM CAUL PLAT. .250"

CORE CLEANING PROCESS
VAPOR DEGREASE: X
OTHER: ______

CORE DRYING PROCESS
20 MIN @ 130 °F

SIZE 19 X 19" WARP 19"
CORE RIBBON DIRECTION 19"
"-FILL " FACE SIDE AGAINST COR.

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: RP-919-158-13

Made By ______ On ______

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. [illegible]

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: [illegible] - 13 - 15

DATE [illegible]

SIZE: 13" x 13" [illegible]

NO. PLIES: [illegible]

TYPE: [illegible]

VAC. ☐ PRESS ☐ AUTOCLAVE ☐

CYCLE INSTRUCTIONS: [illegible] → [illegible] hold @ [illegible] °F.

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
[illegible]	R.T.				[illegible]	[illegible]	[illegible]	[illegible] psi	[illegible]
[illegible]	[illegible]				[illegible]	"	[illegible]	[illegible] psi	
[illegible]	[illegible]				[illegible]	"	[illegible]	[illegible] psi	
[illegible]	[illegible]				[illegible]	"	[illegible]	[illegible] psi	
[illegible]	141°				[illegible]	"	[illegible]	[illegible] psi	
[illegible]	[illegible]				[illegible]	"	[illegible]	[illegible] psi	[illegible]
[illegible]	184°				[illegible]	"	[illegible]	[illegible] psi	
[illegible]	205°				[illegible]	"	[illegible]	[illegible] psi	
11:00	225°				[illegible]	"	[illegible]	[illegible] psi	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible] psi	
[illegible]	[illegible]				[illegible]		[illegible]	[illegible] psi	
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible] psi	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	"	[illegible] psi	[illegible]

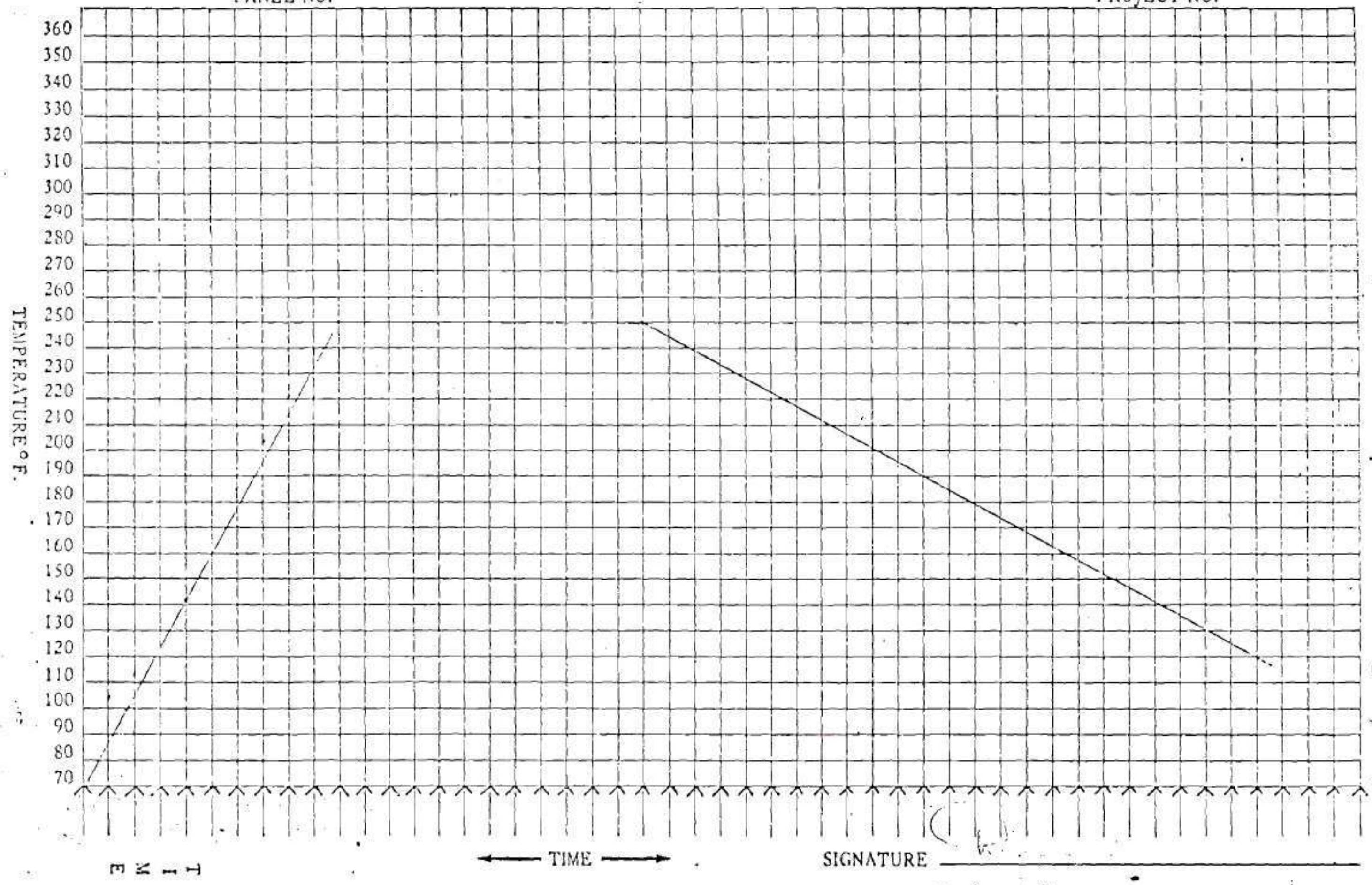
NG-63L REV. 6/24/64

[illegible]

AMERICAN CYA..AMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PANEL NO. [illegible]

PROJECT NO. [illegible]



SIGNATURE

DATE 11-31-67

H8-107 L

PROJECT NO. 95 - J

SANDWICH DATA SHEET

TO ________ FROM ________ DATE 27 NOV 67

Purpose for making the panel STM 77 - 50(.

LOCKHEED [illegible]

Please laminate the following ~~[illegible]~~ panels and report the results to: ________

TYPE A.C.

MATERIAL: 20-919-158

TOOL COVER

BLACK BAG

RELEASE FILM MYLAR

TEFLON

~~[illegible]~~

~~[illegible]~~

3 PLIES PREPREG

CORE $\boxed{\text{1/8" .0009" 5052 N .50" THICK}}$

3 PLIES PREPREG

TEFLON

RELEASE FILM ~~[illegible]~~

BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS

VAPOR DEGREASE: ✓

OTHER: ________

CORE DRYING PROCESS

10 MIN @ 1?? °F

SIZE 19 x 19 WARP 19"

CORE RIBBON DIRECTION 19"

" ________ " FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. → 250°F IN 50' MIN.

Cure Time 60' MIN. HOLD @ 250°F

Cooling Rate TAKE AT LEAST 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ________

REMARKS: ________

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-158-15

Made By [signature] On 11-27-67

/

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 85-J.T.

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: BP-919-158-15

DATE 11-27-67

SIZE: 19" x 19" 19" Warp

NO. PLIES: 3 Top - 3 Bottom

TYPE: AC. VAC. ☐ PRESS ☐ AUTOCLAVE ☑

CYCLE INSTRUCTIONS: R.T. ⟶ 350°F in 50 min. 60 min. hold @ 350°F 2 Hrs To Cool To 125°F. End of Cool Down

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
9:50	R.T.				400	Vent To Atmos	ON/OFF	25 psi	Start.
9:55	104°				400	"	ON/OFF	25 psi	Heat Up Cycle
10:00	114°				400	"	ON/OFF	25 psi	
10:05	133°				400	"	ON/OFF	25 psi	
10:10	144°				400	"	ON/OFF	25 psi	
10:15	167°				400	"	ON/OFF	25 psi	
10:20	184°				400	"	ON/OFF	25 psi	
10:25	199°				400	"	ON/OFF	25 psi	
10:30	217°				400	"		25 psi	
10:35	235°				400	"	ON	25 psi	
10:40	[illegible]				400	"	ON	25 psi	
[illegible]	350°F				400	Vent To Atmos	ON	25 psi	Begin hold @ 350° Cure Cycle
11:40	350°	Start of Cool Down			400	Vent To Atm	OFF	25 psi	2 Hrs. To Cool To 125°F.

HG-63L REV. 6/24/64

[illegible signature]

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

BP. 919 - 158 - 15   JC.   15 - JT

PANEL NO.   PROJECT NO.

SIGNATURE

DATE 11-27-67

PROJECT NO. 9500

SANDWICH DATA SHEET.

FROM ______ DATE 6 DEC '67

Purpose for making the panel STM 22-506

Please laminate the following ______ panels and report TYPE A.C.

the results to:

MATERIAL: BP-919-158

TOOL COVER
MYLAR
RELEASE FILM TEFLON

3-PLIES PREPREG
CORE 1/8 .0009 5052 N .50" THICK.
3-PLIES PREPREG

RELEASE FILM TEFLON
BOTTOM CAUL PLATE .250

CORE CLEANING PROCESS

VAPOR DEGREASE: X

OTHER:

CORE DRYING PROCESS
20 MIN @ 130 °F

SIZE 19 x 19" WARP 19"

CORE RIBBON DIRECTION 19"

"-FILL" FACE SIDE AGAINST CSR

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.)

REMARKS:

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-158-16

Made By [illegible] On 12-6-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95-JJ

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: 919-155-16

DATE 12-6-67

SIZE: 19" x 19" 19" wrap

NO. PLIES: 3 Top — 3 Bottom

TYPE: AC VAC. ☒ PRESS ☐ AUTOCLAVE ☐

CYCLE INSTRUCTIONS: R.T. ——> 250°F in 50 min. Cure hold @ 250°F 2 Hrs. To Cool To 125°F. Fast Cool Down.

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
2:55	R.T.				400	Vent to Atmos.	on/off	25 psi	Start.
3:00	100°				400	"	on/off	25 psi	Heat up Cycle
3:05	109°				400	"	on/off	25 psi	
3:10	131°				400	"	on/off	25 psi	
3:15	147°				400	"	on/off	25 psi	
3:20	169°				400	"	on/off	25 psi	
3:25	175°				400	"	on/off	25 psi	
3:30	199°				400	"	on/off	25 psi	
3:35	217°				400	"	on	25 psi	
3:40	241°				400	"	on	25 psi	
3:45	250°				400	"	on	25 psi	
3:45	250°				400	Vent to Atmos.	on	25 psi	60 min hold @ 250° Cure Cycle
4:45	250	Cool	Down		400	Vent to Atmos	off	25 psi	2 Hrs. To Cool To 125°F.

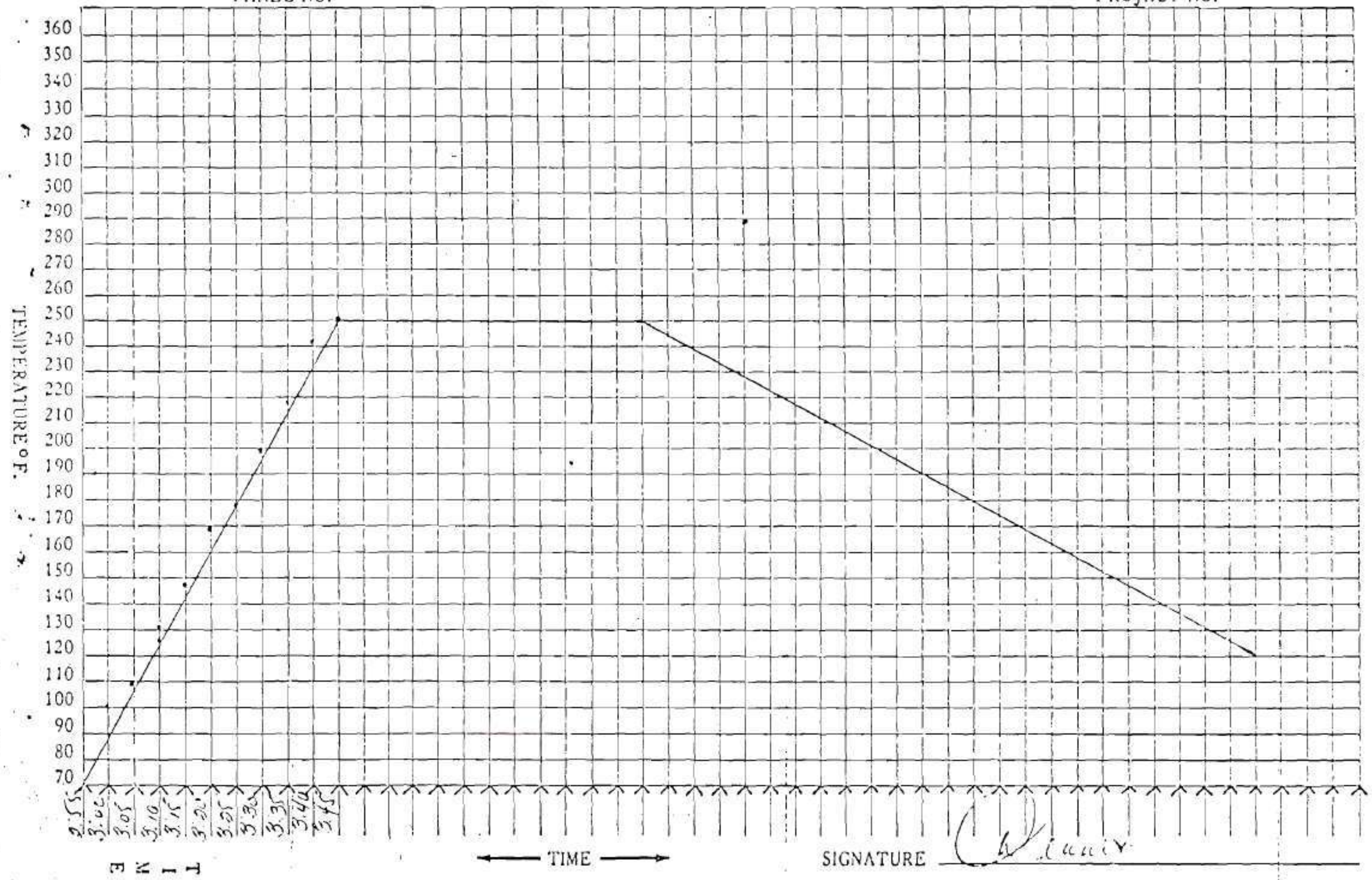
Kimmel

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

919-155-16 — PANEL NO.

AC Panel

95-3-1 — PROJECT NO.



TIME

SIGNATURE C. W. [illegible]

DATE 10-6-67

PROJECT NO. [illegible]

SANDWICH DATA SHEET

TO ______ FROM ______ DATE 7 DEC. 67

Purpose for making the panel STM 22 — 506

Please laminate the following ______ panels and report the results to: ______

TYPE A.C

MATERIAL: RF-919-158

TOOL COVER
MYLAR
RELEASE FILM TEFLON

CORE CLEANING PROCESS

VAPOR DEGREASE: X

OTHER: ______

CORE DRYING PROCESS

20 MIN @ 130 °F

3-PLIES PREPREG

CORE 1/8" .0009" 5052 N .50" THICK.

3-PLIES PREPREG

SIZE ______ WARP

CORE RIBBON DIRECTION ______

"-FILL" FACE SIDE AGAINST CORE

RELEASE FILM TEFLON

BOTTOM CAUL PLAT. .250"

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: RF-919-158-17

Made By [illegible] On 12-7-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. [illegible]

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: 919 - 158 - 17

DATE 12-7-67

SIZE: 19"x19" 19° Warp

NO. PLIES: 3 Top — 3 Bottom

TYPE: RC

VAC. ☐ PRESS ☐ AUTOCLAVE ☑

CYCLE INSTRUCTIONS: R.T. ⟶ 250°F in 50 min. begin hold @ 250°F
2 Hrs. To Cool To 125°F. End Cool Down.

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
10:10	R.T.				400	VENT TO ATMOS.	On/OFF	35 psi	START.
10:15	101°				400	"	ON/OFF	35 psi	Heat up Cycle
10:20	115°				400	"	ON/OFF	35 psi	
10:25	129°				400	"	ON/OFF	35 psi	
10:30	149°				400	"	ON/OFF	35 psi	
10:35	160°				400	"	ON/OFF	35 psi	
10:40	181°				400	"	ON/OFF	35 psi	
10:45	199°				400	"	ON/OFF	35 psi	
10:50	219°				400	"	ON	35 psi	
10:55	237°				400	"	ON	35 psi	
11:00	250°				400	"	ON	35 psi	
11:00	250°	Cure Cycle			400	VENT TO ATMOS.	ON	35 psi	begin hold @ 250 Cure Cycle
13:00	250°	End Cool Down			400	VENT TO ATMOS	OFF	35 psi	2 Hrs. To Cool To 125°F End Cool Down

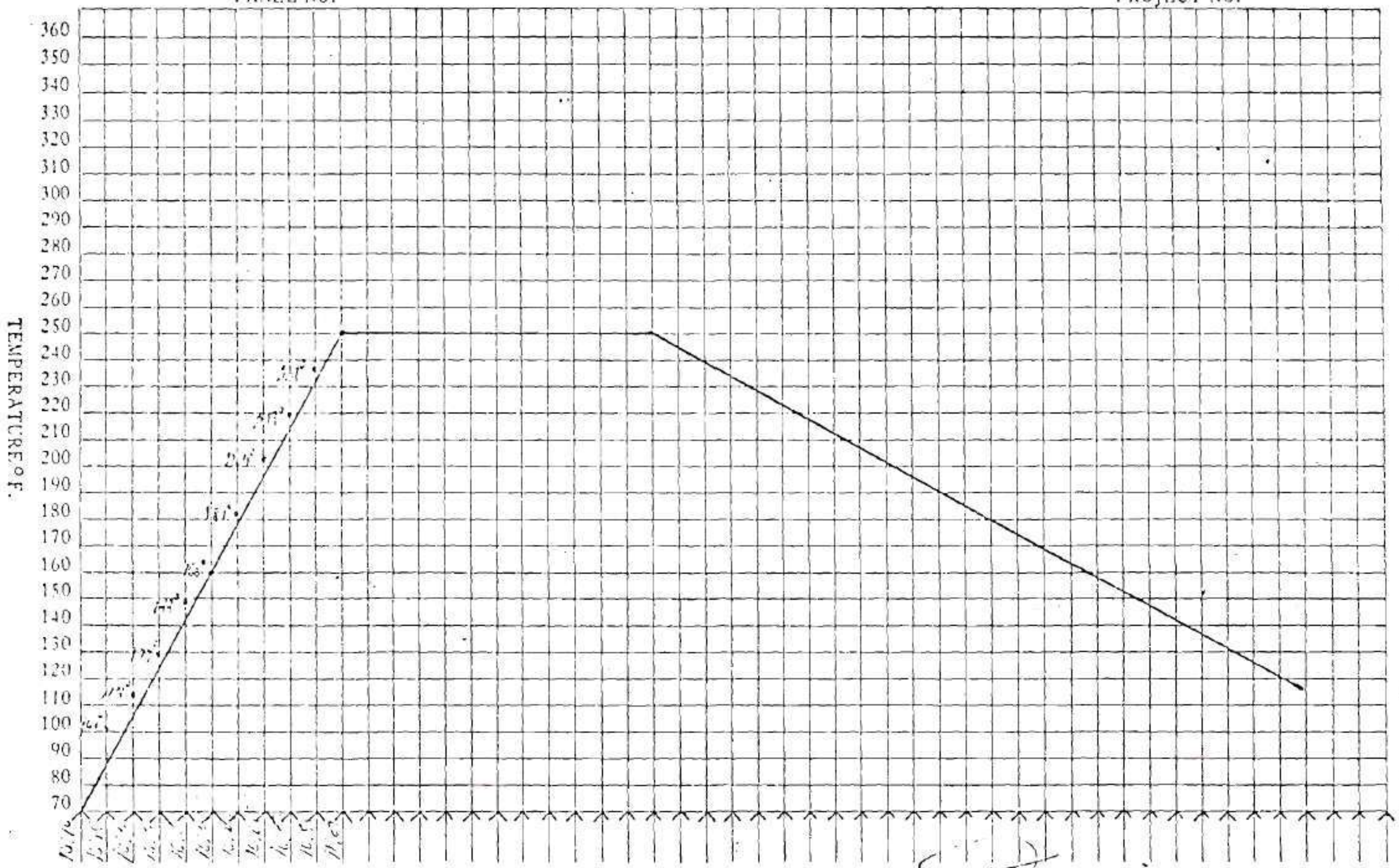
K. [illegible]

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

919-158-11 PANEL NO.

HC Temp

95-JJ PROJECT NO.



← TIME →

SIGNATURE

DATE 12-7-67

HG-107L

PROJECT NO. 95-JJ

SANDWICH DATA SHEET.

TO ______ FROM ______ DATE 8 DEC. 67

Purpose for making the panel STM 22--506

Please laminate the following ~~~~~~~ panels and report TYPE A C

the results to: ______ Roll is in LAB C 9%

MATERIAL: BP-919-158

TOOL COVER

MYLAR

RELEASE FILM TEFLON

3-PLIES PREPREG

CORE 1/8" .0009" 5052 N .50" THICK.

3-PLIES PREPREG

RELEASE FILM TEFLON

BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS

VAPOR DEGREASE: X

OTHER: ______

CORE DRYING PROCESS

20 MIN @ 130 °F

SIZE ______ WARP

CORE RIBBON DIRECTION ______

"-FILL " FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. HOLD AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-158-18

Made By E K T On 12-8-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95TT

BATCH NO:

CURING CYCLE DATA

CUSTOMER [illegible]

LAMINATE NO: BP 919-155-18

DATE 12-5-67

SIZE:

NO. PLIES:

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☒

CYCLE INSTRUCTIONS:

RT→250°F in 50 min; 60 min @ 250°F 25 PSI AIR

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
910	70					[illegible]	[illegible]	25	START
915	100					[illegible]	" "	"	
920	120					[illegible]	ON/OFF	"	
925	134							"	
930	150					"	" "	"	
935	172						" "	"	
940	190					"			
945	214								
950	236								
955	240								
1000	250					"			HOLD 60' @ 250°F
						"			
						"			
1100	251					"	19	25	TURNED STEAM OFF

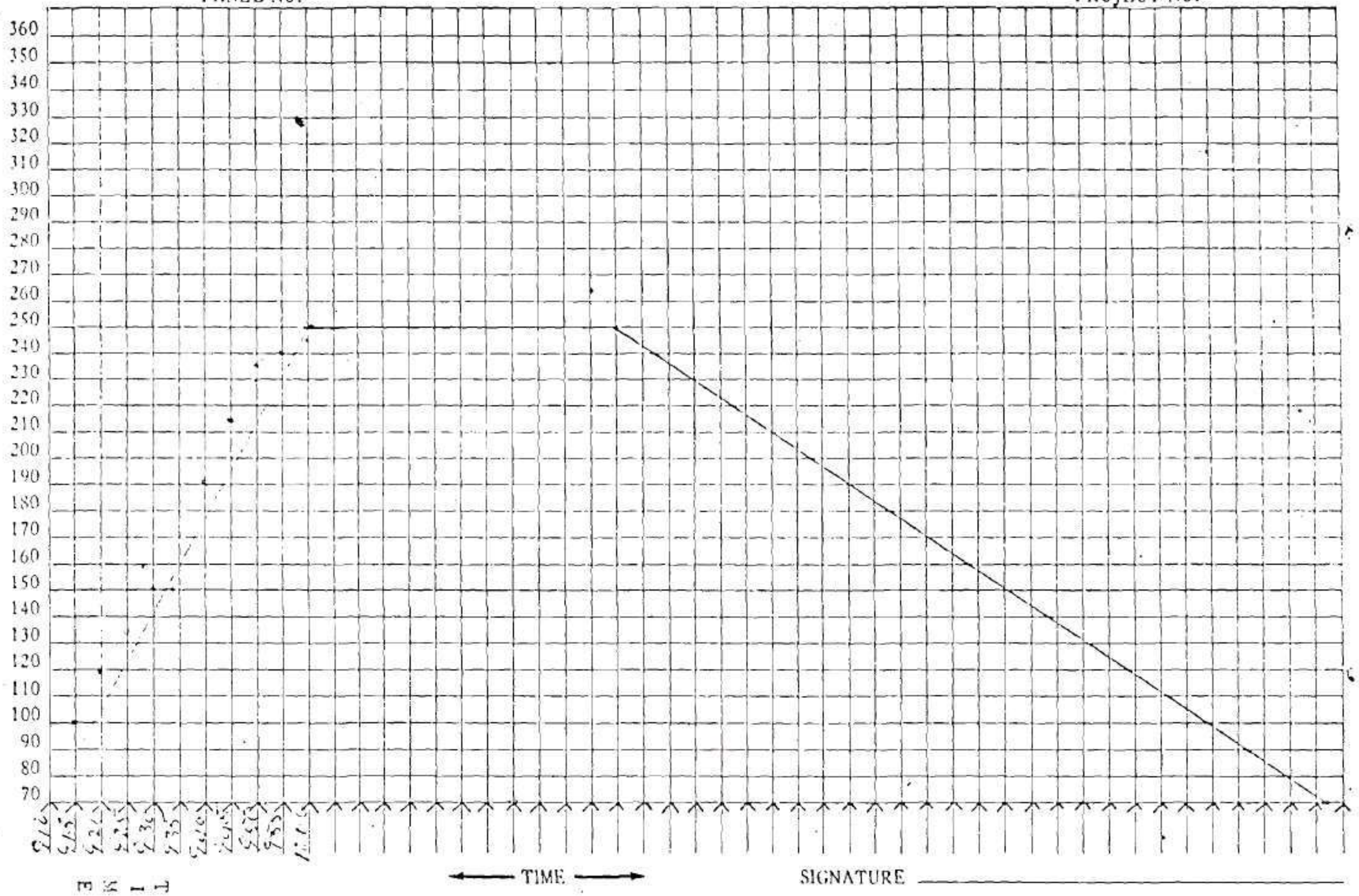
MG-63L REV. 6/24/64

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

BP 919 - 15-8 - 15' ____ PANEL NO.

____

95TJ ____ PROJECT NO.



SIGNATURE ____

DATE ____

HB-107 L

PROJECT NO. ___

SANDWICH DATA SHEET

TO ______ FROM ______ DATE 12-9-67

Purpose for making the panel STM 22-506

LOCKHEED [illegible]

Please laminate the following ~~sandwich~~ panels and report the results to: ______

TYPE A.C.

MATERIAL: BP919-155-20

TOOL COVER	CORE CLEANING PROCESS
BLACK BAG	
RELEASE FILM MYLAR	VAPOR DEGREASE: ✓
TEFLON	OTHER: ______
~~[illegible]~~	
~~[illegible]~~	CORE DRYING PROCESS
3 PLIES PREPREG	MIN @ ___ °F
CORE: 1/8" .0009" 5052 N .50" THICK	
3 PLIES PREPREG	SIZE 19 X 19 WARP 19
	CORE RIBBON DIRECTION 19"
TEFLON	"— — L —" FACE SIDE AGAINST CORE
RELEASE FILM ~~[illegible]~~	
BOTTOM CAUL PLATE .250"	

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. → 250°F IN 50' MIN.

Cure Time 60' MIN. HOLD @ 250°F

Cooling Rate TAKE AT LEAST 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP919-155-20

Made By [illegible] On 12-9-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 9535

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: BP919-155-20

DATE 12-8-67

SIZE: 19X19

NO. PLIES: 5 PLIES TOP & BOT. 1/8" ".0009". " .50 T.

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☒

CYCLE INSTRUCTIONS:

RT - 250°F IN 50 MIN. 60 MIN @ 250°F, 25 PSI AIR

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
8.15	70				400		ON/OFF	25	START
8.20	100				"			"	
8.25	120						" "		
8.30	140				"			"	
8.35	150				"		" "	"	
8.40	167				"				
8.45	191						" "	"	
8.50	210				"			"	
8.55	235						" 10		
9.00	240				"				
9.05	251				"		19	"	HOLD 60 MIN
					400			25	
					"			"	
9.45	251				"		19	"	
					"			"	
					"			"	
					"				
10.05	250				400		OFF	25	END OF HOLD

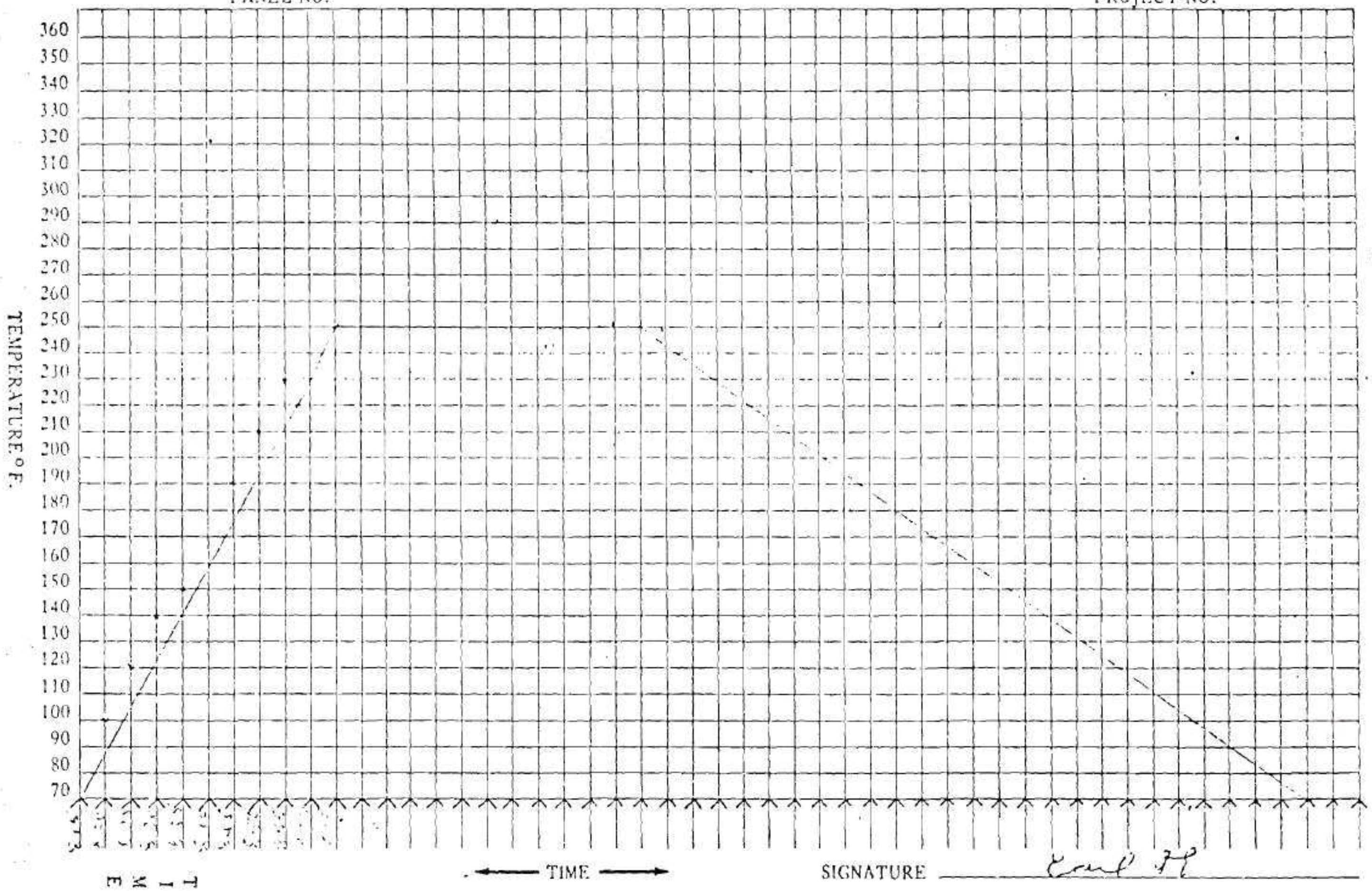
H8-63L REV. 6/24/64

C.I.T. 12-8-67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

EP919-158-20
PANEL NO.

75T
PROJECT NO.



TIME

SIGNATURE [illegible]

DATE 12-8-67

HB-107L
REV

132

PROJECT NO. 95 - J

SANDWICH DATA SHEET

FROM ______ DATE 25 SEPT 67

...king the panel ______

...inate the following ...... panels and report ...ts to: ______

TYPE A.C.

...RIAL: BP - 919 - 113

TOOL COVER
BLACK BAG
RELEASE FILM MYLAR
TEFLON
~~OSNABURG~~
~~.....~~
3 PLIES PREPREG
CORE 3/16 .0025 5052 N .50 T
3 PLIES PREPREG

TEFLON
RELEASE FILM ~~ARMALON~~
BOTTOM CAUL PLATE .250

CORE CLEANING PROCESS
VAPOR DEGREASE: ✓
OTHER: ______

CORE DRYING PROCESS
20 MIN. @ 130 °F.

SIZE 14 x 20" WARP 20"
CORE RIBBON DIRECTION 20"
"FILL "FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50' MIN.

Cure Time 60' MIN. AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

...ARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919 - 113-3

Made By ______ On ______

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95-TT

NO:

CURING CYCLE DATA

CUSTOMER

DATE 9-25-67

ATE NO: BP-919-113-3

: 19"x20"

PLIES:

YPE: AC

VAC. ☐ PRESS ☐ AUTOCLAVE ☑

CYCLE INSTRUCTIONS: R.T → 250°F in 50 min. 60 Min hold @ 250°F. 2 Hrs. To Cool To 125°F. End of Cool Down.

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
10:45	RT.				400	VENT To Atmosphere	OFF	25 psi	START.
10:50	101°				"	"	ON/OFF	25 psi	Heat up Cycle
10:55	114°				"	"	OFF	25 psi	
11:00	126°				"	"	ON/OFF	25 psi	
11:05	149°				"	"	ON/OFF	25 psi	
11:10	165°				"	"	ON/OFF	25 psi	
11:15	186°				"	"	ON/OFF	25 psi	
11:20	200°				"	"	ON/OFF	25 psi	
11:25	220°				"	"	ON	25 psi	
11:30	243°				"	"	ON	25 psi	
11:35	250°				"	"	ON	25 psi	
11:35 11:45	250° 252	60	Min		hold	@	250°F		Hold
12:35		START			of	Cool	Down		START OF Cool Down
		2 Hrs	To		125°F	(End)			

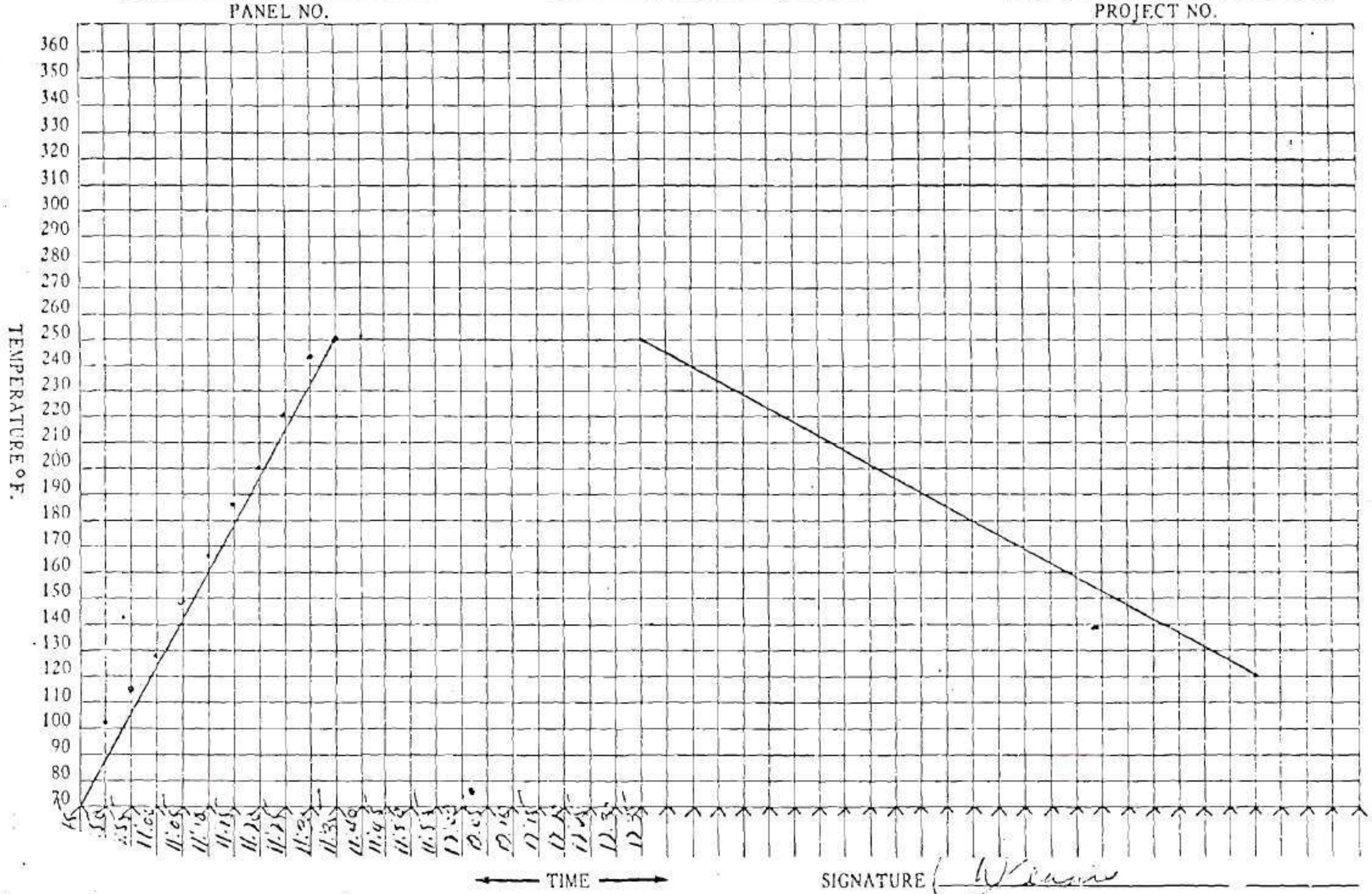
Dennis

HG-63L REV. 6/24/64

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PANEL NO.: BP-919-113-3

PROJECT NO.: 95-T.T



SIGNATURE [illegible]

DATE 9-25-61

PROJECT NO. 95 - J

SANDWICH DATA SHEET

TO ______ FROM ______ DATE 9-26-67

Purpose for making the panel ______

Please laminate the following panels and report

TYPE H.C.

the results to: ______

MATERIAL: BP- 919- 113 - 4

TOOL COVER
BLACK BAG
RELEASE FILM MYLAR
TEFLON

3 PLIES PREPREG
CORE 3/16 .0025" 5052 N .50" T"
3 PLIES PREPREG

RELEASE FILM TEFLON
BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS
VAPOR DEGREASE: ✓
OTHER: ______

CORE DRYING PROCESS
20 MIN. @ 130 °F

SIZE 19 X 20" WARP 20"
CORE RIBBON DIRECTION 20"
" FILL " FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50 MIN.

Cure Time 60 MIN. AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

REMARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-113-4

Made By ______ On ______

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95-TT

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: 919-113-4

DATE 9-26-67

SIZE: 19"x20"

NO. PLIES:

TYPE: AC.

VAC. ☐ PRESS ☐ AUTOCLAVE ☑

CYCLE INSTRUCTIONS: R.T. ⟶ 250°F in 50 min. 60 min hold @ 250°F 2 Hrs. To Cool To 125°F. End of Cool Down

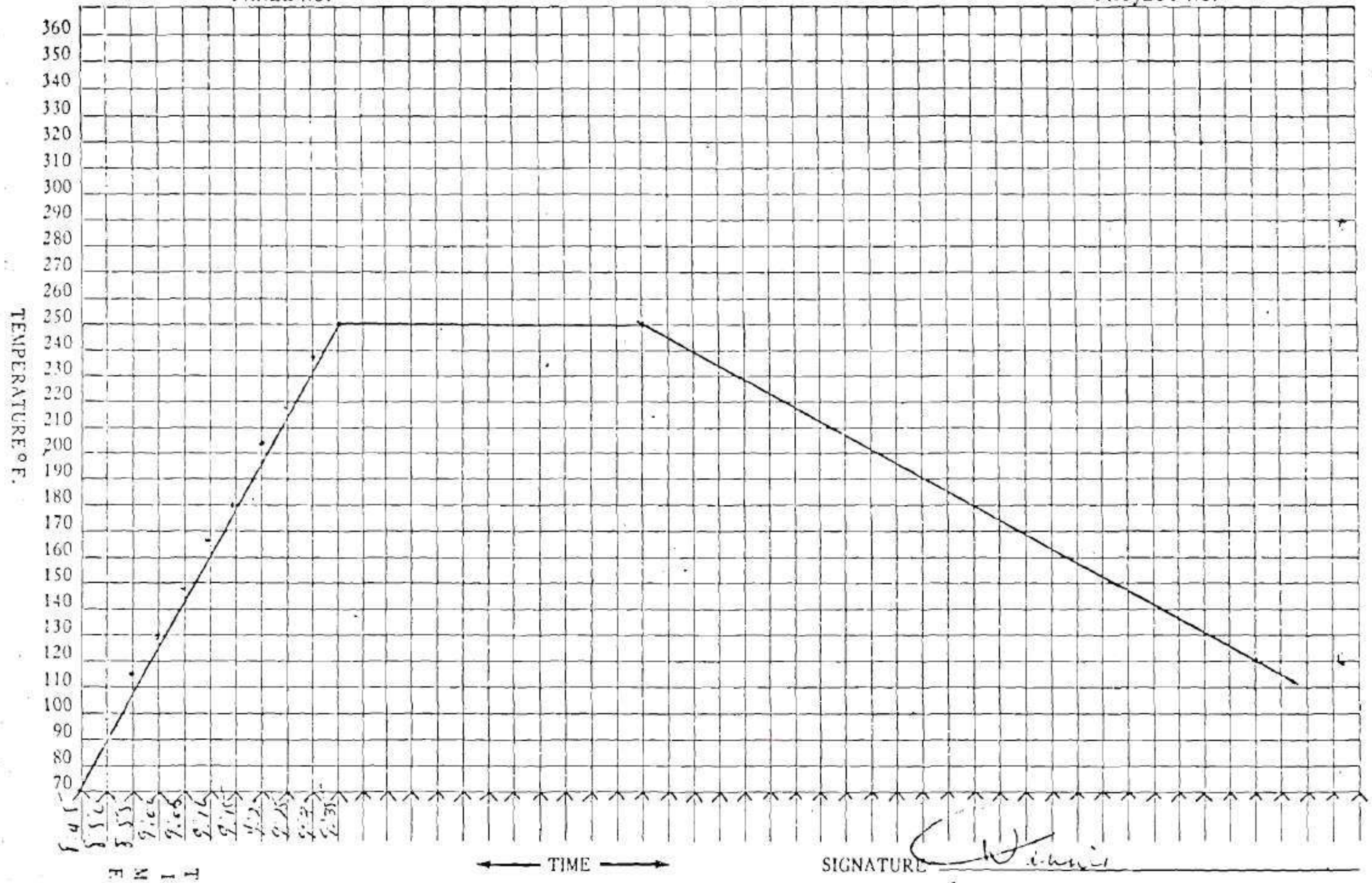
Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
8:45	R.T.				400	VENT TO ATMOS.	OFF	25 psi	START.
8:50	99°				"		ON/OFF	25 psi	Heat up Cycle
8:55	114°				"	"	ON/OFF	25 psi	
9:00	130°				"	"	ON/OFF	20 psi	
9:05	148°				"	"	ON/OFF	25 psi	
9:10	166°				"	"	ON/OFF	25 psi	
9:15	180°				"	"	ON/OFF	25 psi	
9:20	203°				"	"	ON/OFF	25 psi	
9:25	215°				"	"	ON	25 psi	
9:30	235°				"	"	ON	25 psi	
9:35	249°				"	"	ON	25 psi	
9:35			60 min hold @ 250°F						60 min hold
10:35			START OF Cool Down End of Cool Down 125°F						Cool Down

Dinnis

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

919-113-4
PANEL NO.

95-JJ
PROJECT NO.



SIGNATURE [illegible]

DATE 9-26-67

HG-107 L
REV. 8/24/64

PROJECT NO. 95 - J

SANDWICH DATA SHEET

TO ____ FROM ____ DATE 9-27-67

Purpose for making the panel ____

Please laminate the following panels and report the results to: ____

TYPE A.C.

MATERIAL: BP-919-113-

TOOL COVER
BLACK BAG
RELEASE FILM MYLAR
TEFLON

3 PLIES PREPREG
CORE 3/16 .0025" 5052 N .50" T
13 PLIES PREPREG

RELEASE FILM TEFLON
BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS
VAPOR DEGREASE: ____
OTHER: ____

CORE DRYING PROCESS
MIN. @ ____ °F

SIZE ____ WARP
CORE RIBBON DIRECTION ____
"FILL" FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.
Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50' MIN.

Cure Time 60' MIN. AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ____

REMARKS: ____

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: BP-919-113-7

Made By ____ On ____

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

SHIPPED TO LKHD
10-OCT. '67

PROJECT NO. 95-JJ

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: 919 - 113 - 7

DATE 9-27-67

SIZE: 19" x 20"

NO. PLIES: 3 TOP — 3 BOTTOM.

TYPE: AC

VAC. ☐ PRESS ☐ AUTOCLAVE ☑

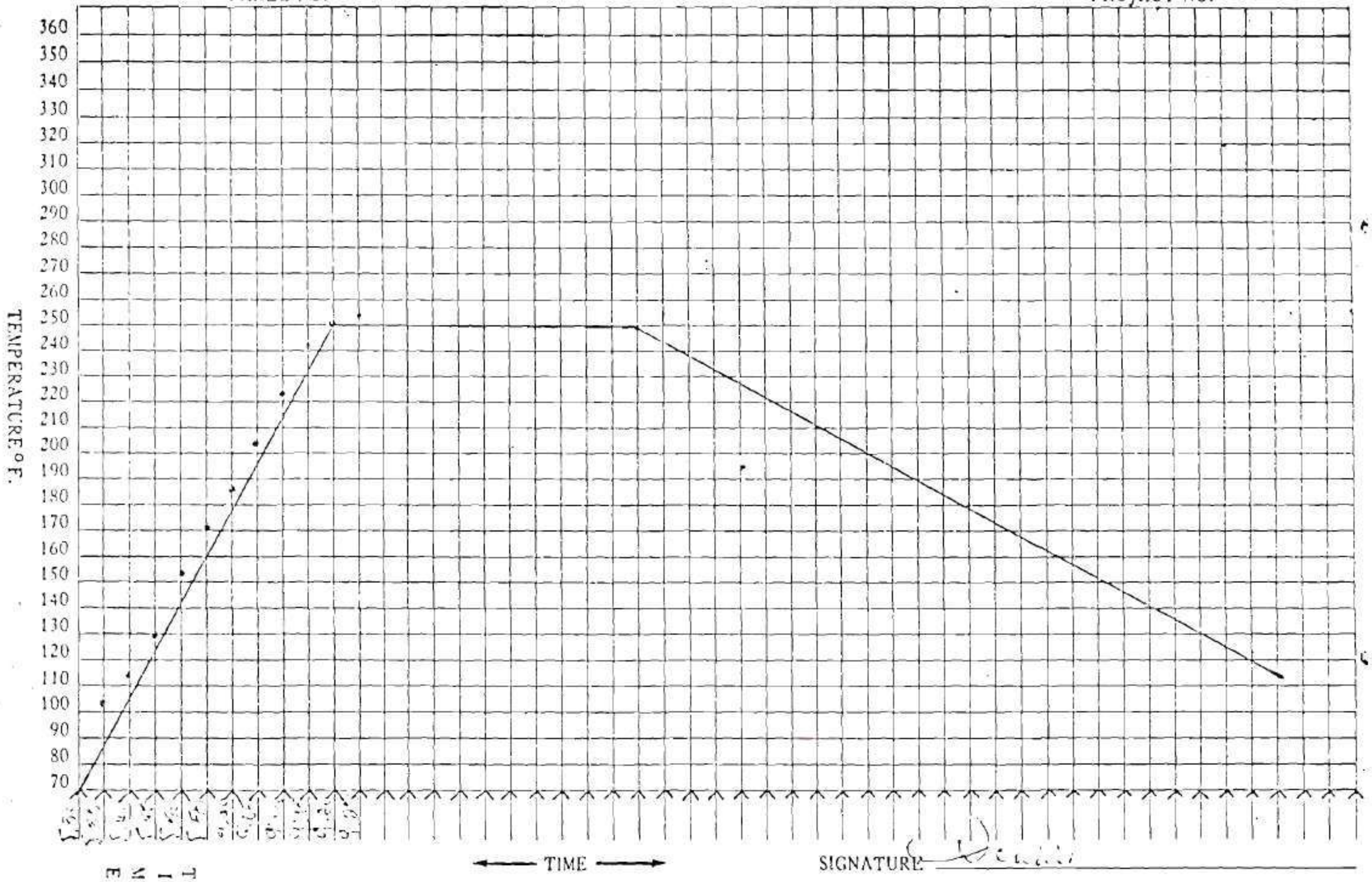
CYCLE INSTRUCTIONS: R.T. → 250°F in 50 min. 60 min hold @ 250°F. 2 HRS. To Cool To 175°F. End of Cool Down.

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
5:30	R.T.				400	Vent To Atmos.	OFF	25 psi	START.
5:35	104°				400	"	on/OFF	25 psi	
5:40	112°				400	"	on/OFF	25 psi	
5:45	129°				400	"	on/OFF	25 psi	Heat up R.T.
5:50	152°				400	"	on/OFF	25 psi	
5:55	171°				400	"	on/OFF	25 psi	
9:00	155°				400	"	on/OFF	25 psi	
9:05	204°				400	"	on/OFF	25 psi	
9:10	222°				400	"	on/~~OFF~~	25 psi	
9:15	241°				400	"	on/~~OFF~~	25 psi	
9:20	250°				400	"	on	25 psi	
9:30		60 mins hold @ 250°F.							Hold
10:30			Start of Cool Down / 2 Hrs. Cool To 175°F End.						Cool Down

Dennis

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

919. 113-7 — PANEL NO.　　J.C.　　95-II — PROJECT NO.



SIGNATURE [illegible]

DATE 9.27.67

HG-107L

PROJECT NO. 95 - 3

SANDWICH DATA SHEET

TO ____ FROM ____ DATE 28 SEPT 67

pose for making the panel

SHIPPED TO LKHD
10 - OCT - '67

Please laminate the following panels and report TYPE A.C.

the results to:

MATERIAL: 3C-919-113

TOOL COVER
BLACK BAG
RELEASE FILM MYLAR
TEFLON
~~OSNABURG~~
~~1003" AERMALON~~
3 PLIES PREPREG
CORE 3/16 .0025" 5052 N .50" T
3 PLIES PREPREG

TEFLON
RELEASE FILM ~~ARMALON~~
BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS
VAPOR DEGREASE: ✓
OTHER:

CORE DRYING PROCESS
7? MIN. @ ? °F
SIZE 9 x 20" WARP
CORE RIBBON DIRECTION
"FILL" FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50' MIN.

Cure Time 60' MIN. AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.)

MARKS:

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: 3C-919-113-8

Made By ____ On ____

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 9577

BATCH NO:

CURING CYCLE DATA

CUSTOMER

DATE 9-25-67

LAMINATE NO:

SIZE:

NO. PLIES:

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☑

CYCLE INSTRUCTIONS:

RT - 250°F in 50 min; 60 min @ 250°F 25 PSI AIR

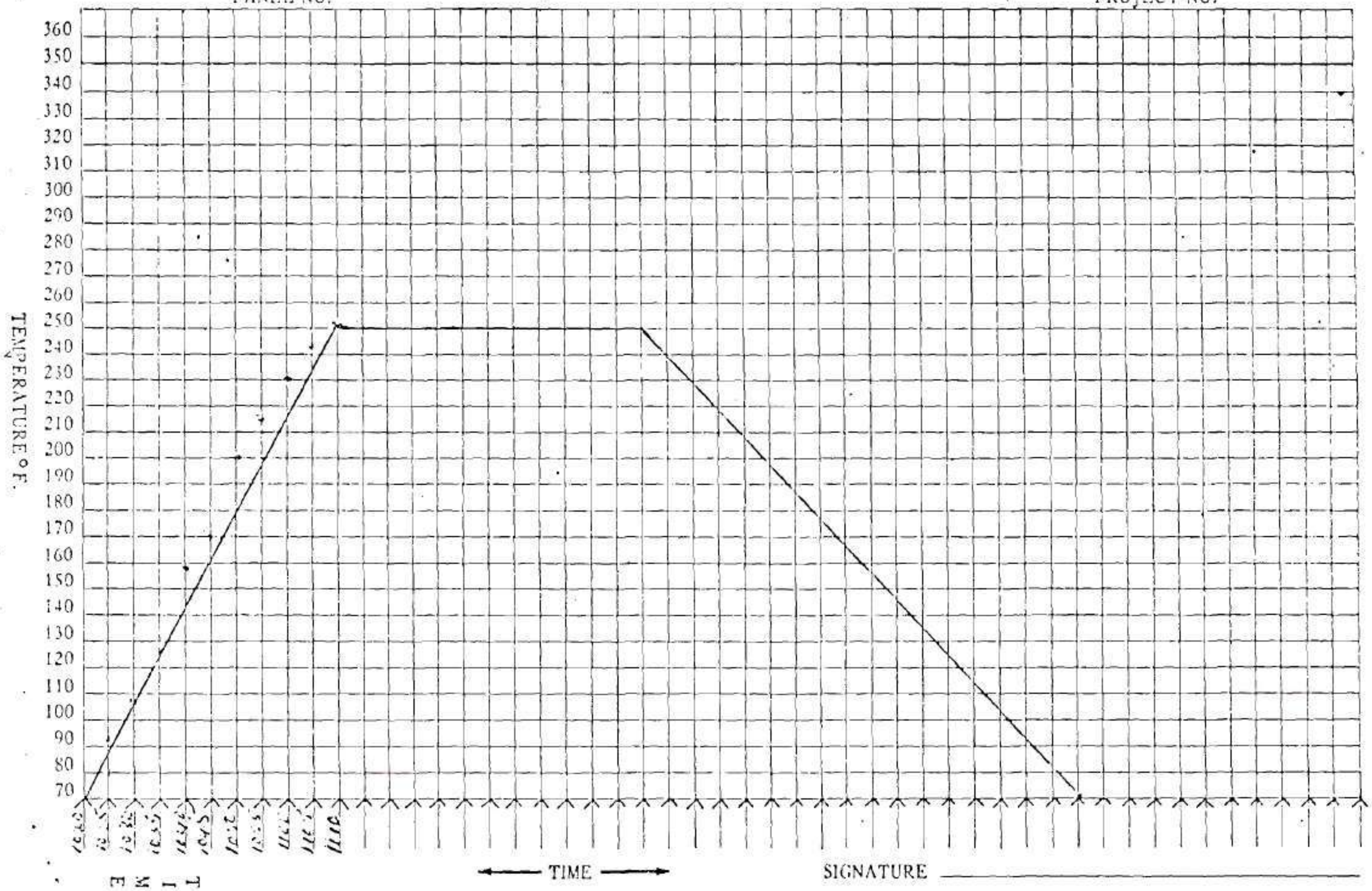
Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
1020	90					VENT.		25 PSI	START.
1025	92					TO.			
1030	108					ATMOS.			
1035	125								
1040	160								
1045	170								
1050	200								
1055	215								
1100	230								
1105	243								
1110	250			HOLD	60 min			25 PSI	
1130	251							25 PSI	

HG-63L REV. 6/24/64

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

BP 919- 173 - 8
PANEL NO.

95JJ
PROJECT NO.



← TIME →

SIGNATURE ______________________

DATE ______________________

HS-107 L
REV. 6/24/64

144

PROJECT NO. 95-57

SANDWICH DATA SHEET

TO ... FROM ... DATE 1 OCT 67

Purpose for making the panel

Please laminate the following panels and report

TYPE AC

the results to:

MATERIAL: 919-113

TOOL COVER

BLACK BAG

RELEASE FILM MYLAR

TEFLON

3 PLIES PREPREG

CORE 3/16 .0025 5052 N .50 T

3 PLIES PREPREG

TEFLON

RELEASE FILM

BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS

VAPOR DEGREASE: ✓

OTHER:

CORE DRYING PROCESS

20 MIN. @ ... °F

SIZE 14 X 20" WARP ...

CORE RIBBON DIRECTION ...

"FILL" FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50' MIN.

Cure Time 60' MIN. AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL DOWN

POST CURE: Time (Hrs.) NONE

Temp. (°F.)

MARKS:

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: 919-113-9

Made By ... On ...

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95-77

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: BP-919-113-9

DATE 10-3-67

SIZE: 19"/20"

SHIPPED TO LKHD.
10 OCT. '67

NO. PLIES: 3 Top 3 Bot.

TYPE: AC

VAC. ☐ PRESS ☐ AUTOCLAVE ☑

CYCLE INSTRUCTIONS: RT. → 250°F in 50 min. 60 min hold @ 250°F. 2 HRS. To cool To 125°F. End of Cool Down

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
8:35	RT.				400	VENT TO ATMOS.	ON/OFF	25 psi	START
8:40	99°				400	"	ON/OFF	25 psi	
8:45	114°				400	"	ON/OFF	25 psi	HEAT UP CYCLE
8:50	126°				400	"	ON/OFF	25 psi	
8:55	149°				400	"	ON/OFF	25 psi	
9:00	166°				400	"	ON/OFF	25 psi	
9:05	180°				400	"	ON/OFF	25 psi	
9:10	205°				400	"	ON/OFF	25 psi	
9:15	223°				400	"	ON	25 psi	
9:20	239°				400	"	ON	25 psi	
9:25	250°				400	"	ON	25 psi	
9:25	250°	60 min hold @ 250°F							Hold @ 250°F 60 min.
10:25		2 HRS. To cool To 125°F End of Cool Down							START OF Cool Down

Dennis

AMERICAN C. .NAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

BP- 919- 113 - 9
PANEL NO.

95-JJ
PROJECT NO.

SIGNATURE

DATE 10 - 3 - 67

HB-107 L

147

PROJECT NO. 95 - J

SANDWICH [illegible]ATA SHEET

TO ______ FROM ______ DATE ______ 67

Purpose for making the panel

SHIPPED TO LKHD.
10 OCT '67

Please laminate the following [illegible] panels and report the results to:

TYPE ______

MATERIAL: [illegible] 919-113

TOOL COVER
BLACK BAG
RELEASE FILM MYLAR
TEFLON
~~[illegible]~~
~~[illegible]~~
3 PLIES PREPREG
CORE 3/16 .0025" 5052 N .50" T"
3 PLIES PREPREG

TEFLON
RELEASE FILM [illegible]
BOTTOM CAUL PLATE .250"

CORE CLEANING PROCESS

VAPOR DEGREASE: ✓

OTHER: ______

CORE DRYING PROCESS
[illegible] MIN. @ [illegible] °F

SIZE [illegible] WARP

CORE RIBBON DIRECTION ______

"FILL" FACE SIDE AGAINST CORE

Pressure: Vac VENT TO ATMOSPHERE Apply At R.T.

Air 25 PSI Apply At R.T.

Heat-Up Rate R.T. TO 250°F IN 50' MIN.

Cure Time 60' MIN AT 250°F

Cooling Rate 2 HRS. TO 125°F

Remove Pressure at END OF COOL CON[illegible]

POST CURE: Time (Hrs.) NONE

Temp. (°F.) ______

[RE]MARKS: ______

PANEL THAT MEETS THE ABOVE OBJECTIVES IS NUMBERED: 919-113-[illegible]

Made By Carl Thorp On 11 Oct 67

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

PROJECT NO. 95 TJ

BATCH NO:

CURING CYCLE DATA

CUSTOMER

LAMINATE NO: 919-113-10

DATE 4 Oct 1.7

SIZE:

NO. PLIES:

TYPE: VAC. ☐ PRESS ☐ AUTOCLAVE ☒

CYCLE INSTRUCTIONS:

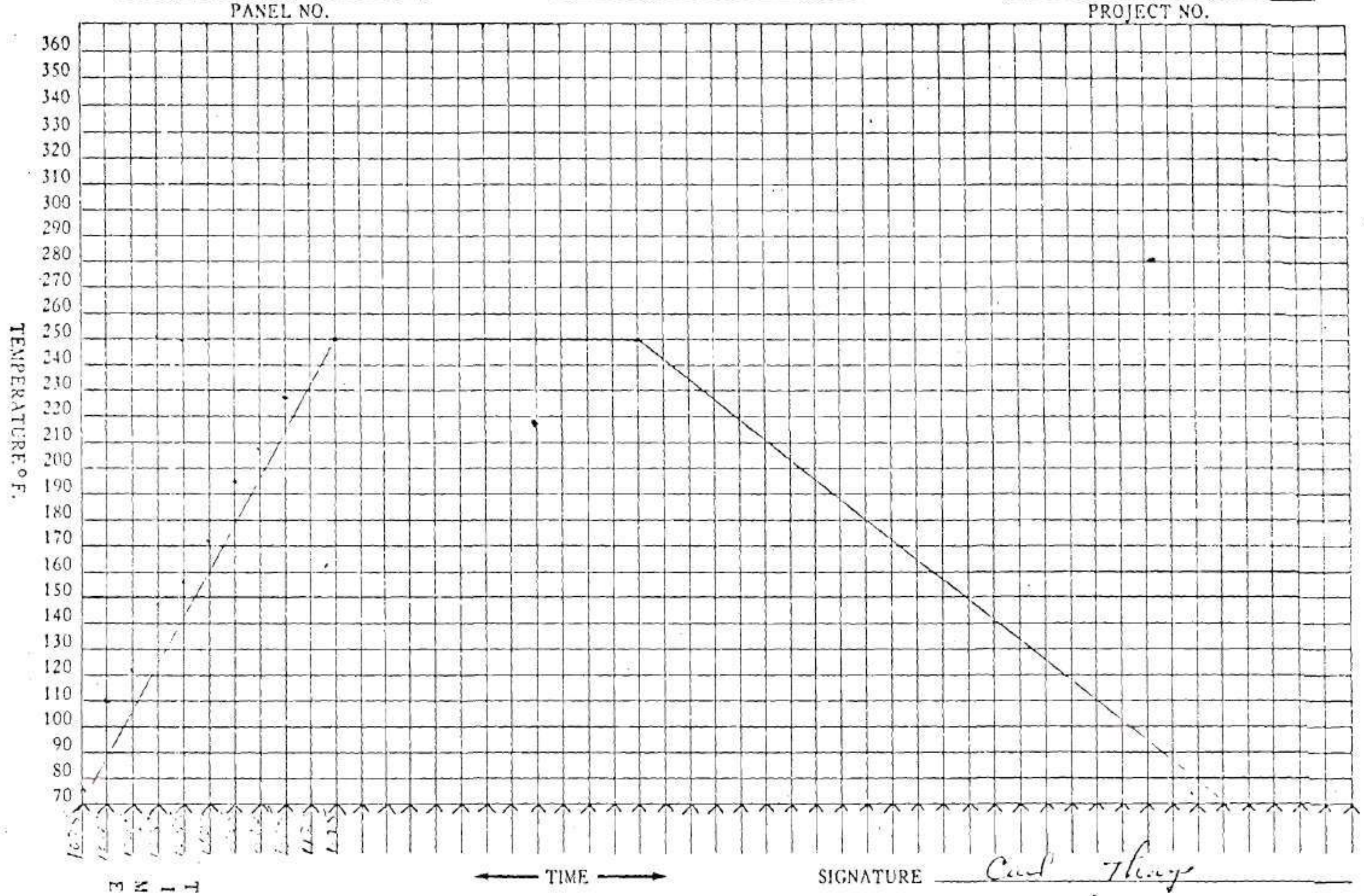
RT - 250°F in 50 min 60 min @ 250°F 25 PSI AIR.

Time	Temp. Stations 1	2	3	4	Gauge Pressure	Vac. Pressure	Steam Pressure	Air Pressure	Remarks
1035	75				400	VENT	ON/OFF	25 PSI	START
1040	110					TO			Plies was warm
1045	121					ATMO.	ON/OFF		when started
1050	148					"			
1055	156								
1100	172						ON/OFF		
05	195						12		
10	205								
15	227								
20	241						19		
25	252				HLD 60 min @ 250°F.			25 PSI	HLD
1130	251				400			25 PSI	
					400				
1135	251								
1225	253				400			25	Cooled.

AMERICAN CYANAMID COMPANY
BLOOMINGDALE DEPARTMENT
HAVRE DE GRACE, MARYLAND

919-113-10
PANEL NO.

95JJ
PROJECT NO.



SIGNATURE Carl Thing

DATE 4 Oct 67

HE-107L

Section 2: Panel Flexural Shear Quality Control Test Data

The following equations were used to calculate failure stresses:

Core Shear Stress =
(psi)

$$\text{(Load)}/\left[\text{(Panel thickness + core thickness)(width)}\right]$$

Face Sheet Failure Stress =
(lbs./inch width/face)

$$\text{(2)(Load)}/\left[\text{(Panel thickness + core thickness)(width)}\right]$$

Core thickness was assumed 0.5 inch

Panel Number	Core Cell	Specimen Number	Width (in.)	Panel Thickness (in.)	Ultimate Load (#)	Core Shear Stress (psi)	Face Failure Stress (#/in.width/face)	Failure Mode
158-2	1/8	1	2.918	0.5420	820	270		Core Shear
		2	2.909	0.5425	790	261		Core Shear
158-15	1/8	1	2.955	0.5390	815	265		Core Shear
		2	2.969	0.5385	825	268		Core Shear
158-17	1/8	1	2.931	0.5374	805	265		Core Shear
		2	2.900	0.5333	740	247		Core Shear
158-18	1/8	1	2.914	0.5389	730	241		Core Shear
		2	2.943	0.5372	725	237		Core Shear
158-20	1/8	1	2.930	0.5400	790	259		Core Shear
		2	2.957	0.5372	760	248		Core Shear
113-3	3/16	1	2.934	0.5460	1615	526		Core Shear
		2	2.933	0.5460	1605	523		Core Shear
113-4	3/16	1	2.946	0.5420	1610	521		Core Shear
		2	2.940	0.5428	1610	525		Core Shear
113-7	3/16	1	3.000	0.5445	1580	504		Core Shear
		2	2.936	0.5444	1570	512		Core Shear
113-8	3/16	1	2.963	0.5430	1635	529		Core Shear
		2	2.990	0.5433	1660	532		Core Shear
113-9	3/16	1	2.978	0.5446	1640	527		Core Shear
		2	2.975	0.5435	1630	525		Core Shear

Panel Number	Core Cell	Specimen Number	Width (in.)	Panel Thickness (in.)	Ultimate Load (#)	Core Shear Stress (psi)	Face Failure Stress (#/in.width/face)	Failure Mode
158-5	1/4	1	2.975	0.5437	1900		1224	Face Compression
		2	2.954	0.5418	1830		1189	Face Compression
158-7	1/4	1	2.950	0.5450	2250		1460	Face Compression
		2	2.935	0.5472	1945		1266	Face Compression
158-9	1/4	1	2.948	0.5415	2140		1394	Face Compression
		2	3.012	0.5435	2040		1298	Face Compression
158-12	1/4	1	2.957	0.5458	1935		1251	Face Compression
		2	2.930	0.5450	1900		1241	Face Compression
158-13	1/4	1	2.958	0.5420	1720		1116	Face Compression
		2	2.954	0.5428	1460		948	Face Compression

APPENDIX 2

RECORDED TEST DATA

Section 1: Laminate Test Data (12 Ply 75DE181/BP919)

Tension

Load Angle	Specimen Number	Width (inch)	Thickness (inch)	Ultimate Load (#)	Ultimate Stress (psi)	Δ Load (#)	Δ Strain (in/in)	Initial Modulus (psi)	Failure Description
0°	1	0.502	0.1232	3750	60,700	1960	0.01	3.17 x 10^6	Net
	2	0.504	0.1254	3700	58,500	2025	0.01	3.20 x 10^6	Net
	3	0.500	0.1250	3790	60,600	2010	0.01	3.22 x 10^6	Net
	4	0.500	0.1228	3560	58,000*	1910	0.01	3.11 x 10^6	Grip
	5	0.504	0.1249	3740	59,500*	2060	0.01	3.27 x 10^6	Grip
	6	0.503	0.1238	3700	59,400	1955	0.01	3.14 x 10^6	Net
	Average				59,800			3.185 x 10^6	
90°	1	0.501	0.1231	2500	40,500	2000	0.01	3.24 x 10^6	Net-Radius
	2	0.503	0.1234	2520	40,600	1910	0.01	3.08 x 10^6	Net-Radius
	3	0.500	0.1230	2570	41,800	1760	0.01	2.86 x 10^6	Net-Radius
	4	0.503	0.1242	2580	41,300	1800	0.01	2.88 x 10^6	Net-Radius
	5	0.502	0.1242	2570	41,300	2035	0.01	3.27 x 10^6	Net-Radius
	6	0.502	0.1246	2550	40,800	1775	0.01	2.84 x 10^6	Net-Radius
	Average				41,050			2.98 x 10^6	
45°	1	0.503	0.1240	1835	29,400	600	0.005	1.92 x 10^6	Net
	2	0.500	0.1242	1645	26,500	480	0.005	1.55 x 10^6	Net-Radius
	3	0.501	0.1226	1445	23,500*	534	0.005	1.74 x 10^6	Net-Radius
	4	0.502	0.1241	1700	27,300	584	0.005	1.87 x 10^6	Net-Radius
	5	0.502	0.1240	1755	28,200	514	0.005	1.65 x 10^6	Net
	6	0.502	0.1237	1590	25,600	470	0.005	1.51 x 10^6	Net-Radius
	Average				26,750			1.71 x 10^6	

*Not used in average, failure unacceptable or measurement suspect

Compression

Load Angle	Specimen Number	Width (inch)	Thickness (inch)	Ultimate Load (#)	Ultimate Stress (psi)	Δ Load (#)	Gage Length (inch)	Δ Strain (in/in)	Initial Modulus (psi)	Failure Description
0°	1	0.704	0.1232	5720	66,000	3000	1.071	0.00934	3.70×10^6	Center
	2	0.700	0.1258	5680	64,500	2970	1.071	0.00934	3.61×10^6	Center
	3	0.703	0.1263	5870	66,100	2980	1.071	0.00934	3.59×10^6	Center
	4	0.704	0.1235	5400	62,100	2900	1.080	0.00926	3.60×10^6	Center
	5	0.704	0.1245	5420	61,900	2900	1.073	0.00932	3.55×10^6	Center
	6	0.703	0.1250	5610	63,800	2680	1.068	0.00936	3.26×10^6	Center
	Average				64,100				3.55×10^6	
90°	1	0.702	0.1206	4370	51,600	712	1.040	0.00240	3.50×10^6	Center
	2	0.700	0.1207	4340	51,400	1525	1.047	0.00478	3.78×10^6	Center*
	3	0.700	0.1210	4190	49,500	1350	1.053	0.00475	3.36×10^6	Center
	4	0.701	0.1207	4440	52,500	1310	1.062	0.00471	3.29×10^6	Center
	5	0.700	0.1208	4160	49,200	1690	1.045	0.00478	4.18×10^6	Center*
	6	0.700	0.1214	4130	48,600	1250	1.053	0.00475	3.10×10^6	Center
	Average				50,500				3.31×10^6	
45°	1	0.702	0.1212	1660	19,500					ES
	2	0.703	0.1239	1880	21,600	840	1.045	0.00478	2.02×10^6	Support End
	3	0.702	0.1203	1900	22,500	820	1.065	0.00469	2.07×10^6	At Clamp
	4	0.702	0.1245	1820	20,800					ES
	5	0.702	0.1250	2040	23,300	1040	1.045	0.00478	2.48×10^6*	At Clamp
	6	0.702	0.1200	1850	22,000					Support End
	Average				21,600				2.05×10^6	
45° Rerun	1	0.688	0.1152	1700	21,400	1190	1.055	0.00948	1.58×10^6	ES
	2	0.632	0.1152	1530	21,000	1260	1.046	0.00956	1.81×10^6	ES
	3	0.688	0.1150	1600	20,200	1595	1.042	0.00960	2.10×10^6	ES
	4	0.683	0.1148	1620	20,700	1160	1.064	0.00940	1.57×10^6	ES
	5	0.669	0.1145	1530	20,000	1145	1.050	0.00952	1.57×10^6	ES
	Average				20,700				1.73×10^6	

Compression Cont'd

Load Angle	Specimen Number	Width (inch)	Thickness (inch)	Ultimate Load (#)	Ultimate Stress (psi)	Δ Load (#)	Gage Length (inch)	Δ Strain (in/in)	Initial Modulus (psi)	Failure Description
30°	1	0.687	0.1137	1830	23,400	1540	1.068	0.00936	2.11×10^6	ES
	2	0.689	0.1140	1880	24,000	1500	1.065	0.00939	2.03×10^6	ES
	3	0.687	0.1142	1890	24,100	1360	1.056	0.00947	1.83×10^6	ES
	4	0.688	0.1147	1840	23,300	1685	1.064	0.00940	2.27×10^6	ES
	5	0.687	0.1150	1820	23,000	1460	1.059	0.00944	1.96×10^6	ES
	Average				23,600				2.04×10^6	
60°	1	0.687	0.1143	1800	22,900	1755	1.067	0.00937	2.39×10^6	ES
	2	0.687	0.1140	1810	23,100	1425	1.059	0.00944	1.93×10^6	ES
	3	0.686	0.1140	1780	22,800	1625	1.061	0.00943	2.20×10^6	ES
	4	0.686	0.1142	1840	23,500	1625	1.065	0.00939	2.21×10^6	ES
	5	0.686	0.1142	1840	23,500	1730	1.060	0.00943	2.34×10^6	ES
	Average				23,200				2.21×10^6	

Note: ES - Some 30°, 45° and 60° specimens failed in an edgewise general instability mode.

Flexure (3-Point Loading, 2-Inch Span)

Manufacturer/Material Code: AC American Cyanamid 75DE181/BP919
LG Lockheed-Georgia 75DE181/BP919
3M 3M Company 75DE181/SP275A

Manufacturer	Specimen Number	Width (inch)	Thickness (inch)	Ultimate Load (#)	Ultimate Modulus of Rupture (psi)	Δ Load (#)	Δ Deflection (inch)	Initial Modulus (psi)
AC	1	0.902	0.1211	365	82,800	252	0.1	3.15×10^6
AC	2	0.920	0.1213	370	82,000	259	0.1	3.15×10^6
AC	3	0.936	0.1208	381	83,700	257	0.1	3.11×10^6
AC	4	0.929	0.1202	375	83,800	258	0.1	3.20×10^6
AC	5	0.932	0.1206	378	83,700	262	0.1	3.20×10^6
AC	6	0.929	0.1205	381	84,700	256	0.1	3.15×10^6
AC	7	0.937	0.1199	376	83,700	254	0.1	3.14×10^6
	Average				83,500			3.16×10^6
LG	5-1	0.935	0.1146	358	87,400	238.5	0.1	3.39×10^6
LG	5-2	0.937	0.1149	360	87,300	247.5	0.1	3.48×10^6
LG	5-3	0.939	0.1144	361	88,100	245.5	0.1	3.49×10^6
LG	5-4	0.937	0.1146	352	85,800	244.5	0.1	3.47×10^6
LG	5-5	0.937	0.1148	357	86,700	248	0.1	3.50×10^6
LG	5-6	0.935	0.1152	362	87,500	249	0.1	3.48×10^6
LG	5-7	0.936	0.1144	358	87,700	249	0.1	3.55×10^6
LG	5-8	0.937	0.1148	351	85,200	248.5	0.1	3.50×10^6
	Average				87,000			3.48×10^6

Flexure Cont'd

Manufacturer	Specimen Number	Width (inch)	Thickness (inch)	Ultimate Load (#)	Ultimate Modulus of Rupture (psi)	Δ Load (#)	Δ Deflection (inch)	Initial Modulus (psi)
3M	6-1	0.934	0.120	382	85,200	272	0.1	3.37×10^6
3M	6-2	0.935	0.118	365	84,100	260	0.1	3.39×10^6
3M	6-3	0.935	0.121	380	83,300	268	0.1	3.24×10^6
3M	6-4	0.938	0.120	372	82,600	266	0.1	3.34×10^6
3M	6-5	0.935	0.120	383	85,300	270	0.1	3.34×10^6
3M	6-6	0.937	0.119	364	82,300	260.5	0.1	3.30×10^6
3M	6-7	0.936	0.120	385	85,700	269	0.1	3.33×10^6
	Average				84,100			3.32×10^6

Section 2: Sandwich Quality Control Test Data

Flatwise Tension

Specimen Number	Type Core	Panel Number	Average Diameter (inch)	Ultimate Load (#)	Ultimate Stress (psi)	Failure Mode
1	1/8-.0009"-	BP919-158-16	1.98	2800	909	Load Block Bond - Core Fracture
2	5052-NP		2.01	2860	901	Core Tension
3	-.50"		2.02	2960	924	Core Tension
4	(3.7#/ft^3)		2.02	2960	924	Core Tension
5			2.00	2880	917	Core Tension
Average					915	
1	3/16-.0025"-	BP919-113-10	2.01			
2	5052-NP		2.02	2170	677	Adhesive
3	-.50"		2.00	2250	716	Adhesive
4	(6.8#/ft^3)		1.98	2000	650	Adhesive
5			2.01	2200	693	Adhesive
Average					684	
1	1/4 -.004"-	BP919-158-6	2.02	1620	505*	Load Block Bond
2	5052-NP		2.00	2720	866	Adhesive
3	-.50"		2.01	2650	835	Adhesive
4	(8#/ft^3)		2.02	2650	827	Adhesive
5			2.03	2910	899	Adhesive
Average					857	

* Not used in average, failure unacceptable

Flatwise Compression

Specimen Number	Type Core	Panel Number	Average Diameter (inch)	Ultimate Load (#)	Ultimate Stress (psi)	Failure Mode
1	1/8-.0009"-	BP919-158-16	1.990	1185	381	Core Buckle
2	5052-NP-		1.990	1130	363	Core Buckle
3	0.5"		1.915	1055	366	Core Buckle
4	(3.7#/ft^3)		1.980	1260	409	Core Buckle
5			2.010	1335	421	Core Buckle
Average					388	
1	3/16-.0025"	BP919-113-10	2.035	3070	944	Core Buckle
2	5052-NP-		2.020	2940	917	Core Buckle
3	0.5"		2.030	2980	921	Core Buckle
4	(6.8#/ft^3)		2.040	3020	924	Core Buckle
5			2.000	2950	939	Core Buckle
Average					929	
1	1/4-.004"	BP919-158-6	2.030			
2	5052-NP-		2.015	5570	1747	Core Buckle
3	0.5"		2.025	5500	1708	Core Buckle
4	(8.0#/ft^3)		2.020	5450	1700	Core Buckle
5			2.035	5420	1666	Core Buckle
Average					1705	

Flexural Shear

Specimen Number	Core Type	Panel Number	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Core Shear Stress (psi)	Face Stress (#/in-width/face)	Deflec-tion at 150# (inch)	Failure Mode
1	1/8-.0009"-	BP919-158-16	2.960	0.540	725	236		0.0160	Core Shear
2	5052-NP-		2.965	0.538	665	216		0.0155	Core Shear
3	0.5"		3.030	0.538	760	242		0.0170	Core Shear
4	(3.7#/ft)		2.995	0.539	740	238		0.0170	Core Shear
5			2.990	0.540	725	233		0.0170	Core Shear
Average						233			
1	3/16-.0025"-	BP919-113-10	2.980	0.545	1520	488		0.0165	Core Shear
2	5052-NP-		2.955	0.546	1490	482		0.0145	Core Shear
3	0.5"		2.955	0.546	1440	466		0.0135	Core Shear
4	(6.8#/ft)		2.995	0.547	1440	459		0.0150	Core Shear
5			3.035	0.545	1490	470		0.0160	Core Shear
Average						473			
1	1/4-.004"-	BP919-158-6	3.030	0.545	1820		1150	0.0150	Face Comp.
2	5052-NP-		2.940	0.544	1620		1056	0.0140	Face Comp.
3	0.5"		2.960	0.544	1660		1074	0.0170	Face Comp.
4	(8.0#/ft)		2.955	0.544	1900		1232	0.0135	Face Comp.
5			2.950	0.543	1900		1235	0.0150	Face Comp.
6			3.020	0.544	1890		1199	0.0145	Face Comp.
Average							1158		

Note: (1) Core thickness taken as 0.5"
(2) Failure stress equations same as those in Appendix 1, Section 2

Section 3: Edgewise Compression Strength Test Data

*Value not used in averages

Load Angle	Core Cell Size	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
0°	1/8	1	1.940	0.544	3750	966	Arithmatic Average: 955 #/in-width/face; B Allowable Value: 843 #/in.-width/face; Standard Deviation: 50.5	Single Face
		2	1.940	0.543				
		3	1.922	0.545	3560	926		End Failure
		4	1.927	0.544	3530	916		Single Face
		5	1.916	0.543	3620	945		Single Face
		6	1.920	0.546	3430	893		Single Face
		7	1.924	0.543	3520	915		Clamp Area
		8	1.928	0.543	3800	985		Single Face
		9	1.936	0.544	3450	891		End Crush
		10	1.928	0.542	4030	1045		Double Face
		11	1.942	0.542	4000	1030		Double Face
		12	1.919	0.544	3360	876*		Clamp Area
		13	1.944	0.542	3740	962		Double Face
		14	1.937	0.542	3840	991		Single Face
30°	1/8	1	1.936	0.541	2050	529	Arithmatic Average: 535 #/in-width/face; B Allowable Value: 501 #/in.-width/face; Standard Deviation: 16.2	Single Face
		2	1.941	0.543	2000	515		Double Face
		3	1.901	0.541	2160	568		Clamp Area
		4	1.931	0.542	1940	502		Double Face
		5	1.935	0.543	2060	532		Single Face
		6	1.919	0.541	2120	552		Double Face
		7	1.862	0.542	1980	531		Single Face
		8	1.936	0.539	2100	542		Single Face
		9	1.934	0.540	2130	551		Double Face
		10	1.903	0.542	1990	523		Double Face
		11	1.896	0.545	2040	538		Single Face
		12	1.916	0.539	2070	540		Clamp Area
		13	1.939	0.543	2070	534		Double Face
		14	1.919	0.541	2070	539		Double Face

Load Angle	Core Cell Size	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
45°	1/8	1	1.962	0.540	1870	477	Arithmatic Average: 474 #/in-width/face B Allowable Value: 462 #/in-width/face Standard Deviation: 5.2	Double Face
		2	1.930	0.538				
		3	1.920	0.539	1810	471		Double Face
		4	1.912	0.538	1840	481		Single Face
		5	1.900	0.538	1790	471		Double Face
		6	1.902	0.539	1790	471		Single Face
		7	1.931	0.538	1860	482		Double Face
		8	1.955	0.539	1830	468		Double Face
		9	1.965	0.540	1830	466		Double Face
		10	1.946	0.536	1830	470		Single Face
		11	1.940	0.539	1830	472		Double Face
		12	1.925	0.537	1810	470		Double Face
		13	1.914	0.537	1830	478		Single Face
		14	1.911	0.538	1830	479		Single Face
60°	1/8	1	1.910	0.540	1900	497	Arithmatic Average: 504 #/in-width/face B Allowable Value: 486 #/in-width/face Standard Deviation: 8.6	Single Face
		2	1.906	0.541	1910	501		Clamp Area
		3	1.887	0.542	1890	501		Clamp Area
		4	1.904	0.540	1870	491		Single Face
		5	1.939	0.544	1950	503		Single Face
		6	1.888	0.542	1910	506		Double Face
		7	1.883	0.545	1940	515		Single Face
		8	1.895	0.544	1910	504		Double Face
		9	1.908	0.542	1890	495		Clamp Area
		10	1.925	0.544	1980	514		Clamp Area
		11	1.891	0.542	1870	494		Single Face
		12	1.905	0.542	1950	512		Single Face
		13	1.918	0.543	1990	519		Single Face
		14	1.884	0.542	1920	510		Single Face

Load Angle	Core Cell Size	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
90°	1/8	1	1.897	0.541	3600	949	Arithmatic Average: Face Failure: 905 Shear Instability: 757 B Allowable Value: Face: 747 Shear: 691 Standard Deviation: Face: 56.9 Shear: 19.1	Double Face
		2	1.900	0.540	3660	963		Double Face
		3	1.860	0.540	2710	728		Shear Instability
		4	1.884	0.541	2880	764		Shear Instability
		5	1.904	0.540	2940	772		Shear Instability
		6	1.875	0.540	2810	749		Shear Instability
		7	1.921	0.542	3010	783*		Clamp Area
		8	1.922	0.541	3730	970		Double Face
		9	1.922	0.540	3300	858		Double Face
		10	1.918	0.540	2970	774		Shear Instability
		11	1.853	0.540	3200	863		Single Face
		12	1.891	0.540	3130	828		Double Face
		13	1.921	0.538	3020	786*		Clamp Area
		14	1.907	0.538	3450	905		Double Face
0°	3/16	1	1.955	0.544	5500	1407	Arithmatic Average: 1230 #/in-width/face B Allowable Value: 919 #/in-width/face Standard Deviation: 112.1	Double Face
		2	1.942	0.543				
		3	1.929	0.544	4980	1291*		Strain Gaged
		4	1.943	0.543				
		5	1.950	0.544	4880	1251		Single Face
		6	1.921	0.542	3820	994*		Clamp Area
		7	1.922	0.543	4130	1074*		Strain Gaged
		8	1.930	0.542	4230	1096*		Strain Gaged
		9	1.941	0.543	4500	1159*		Strain Gaged
		10	1.950	0.543	4900	1256		Double Face
		11	1.925	0.543	4780	1242		Double Face
		12	1.931	0.542	4600	1191		Double Face
		13	1.940	0.543	4790	1235		Single Face
		14	1.947	0.542	4000	1027		Single Face

Load Angle	Core Cell Size	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
30°	3/16	1	1.895	0.542	2420	639	Arithmatic Average: 608 #/in-width/face B Allowable Value: 576 #/in-width/face Standard Deviation: 13.7	Double Face
		2	1.935	0.543	2400	620*		Strain Gaged
		3	1.947	0.545	2650	680*		Strain Gaged
		4	1.943	0.543	2440	628*		Strain Gaged
		5	1.938	0.542	2400	619*		Strain Gaged
		6	1.940	0.544	2420	624		Double Face
		7	1.916	0.543	2300	600		Double Face
		8	1.941	0.543	2300	592		Double Face
		9	1.970	0.542	2400	609		Double Face
		10	1.923	0.542	2320	603		Single Face
		11	1.916	0.543	2300	600		Double Face
		12	1.925	0.542	2310	600		Clamp Area
		13	1.933	0.542	2340	605		Double Face
		14	1.931	0.543	2350	608		Double Face
45°	3/16	1	1.935	0.546	2310	597	Arithmatic Average: 568 #/in-width/face B Allowable Value: 537 #/in-width/face Standard Deviation: 12.3	Single Face
		2	1.956	0.547				
		3	1.936	0.546	2270	586*		Strain Gaged
		4	1.934	0.546	2280	589*		Strain Gaged
		5	1.927	0.546	2180	566		Single Face
		6	1.905	0.546	2230	585*		Strain Gaged
		7	1.940	0.546	2170	559		Single Face
		8	1.959	0.546	2190	559		Single Face
		9	1.962	0.546	2250	573		Single Face
		10	1.912	0.546	2130	557		Single Face
		11	1.905	0.545	2170	570		Single Face
		12	1.921	0.545	2180	567		Single Face
		13	1.930	0.546	2190	567*		Strain Gaged
		14	1.935	0.545	2170	561		Single Face

Load Angle	Core Cell Size	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
60°	3/16	1	1.940	0.545	2480	639	Arithmatic Average: 601 #/in-width/face B Allowable Value: 526 #/in-width/face Standard Deviation: 31.8	Double Face
		2	1.953	0.543	2250	576*		Strain Gaged
		3	1.915	0.542	2250	587*		Strain Gaged
		4	1.932	0.545	2600	673*		Strain Gaged
		5	1.905	0.543	2270	596*		Strain Gaged
		6	1.939	0.543	2240	578		Single Face
		7	1.912	0.546	2260	591		Clamp Area
		8	1.910	0.543	2260	592		Double Face
		9	1.918	0.542	2160	563		Double Face
		10	1.934	0.546	2500	646		Double Face
		11	1.944	0.543	2300	592		Double Face
		12	1.929	0.543	2190	568		Single Face
		13	1.936	0.546	2510	648		Double Face
		14	1.940	0.545	2300	592		Double Face
90°	3/16	1	1.934	0.545	4170	1078	Arithmatic Average: 986 #/in-width/face B Allowable Value: 852 #/in-width/face Standard Deviation: 48.1	Double Face
		2	1.946	0.544	3520	904*		Strain Gaged
		3	1.975	0.544	3860	977*		Strain Gaged
		4	1.940	0.544	3500	902*		Strain Gaged
		5	1.930	0.544	3400	881*		Strain Gaged
		6	1.950	0.543	3340	856*		Clamp Area
		7	1.909	0.544	3020	791*		Clamp Area
		8	1.904	0.544	3640	956		Double Face
		9	1.900	0.544	3820	1005		Double Face
		10	1.946	0.544	3850	989		Double Face
		11	1.944	0.544	3600	926		Double Face
		12	1.945	0.544	3820	982		Double Face
		13	1.938	0.544	3330	859*		Clamp Area
		14	1.932	0.544	3720	963		Double Face

Load Angle	Core Cell Size	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
0°	1/4	1	1.895	0.542	4000	1055	Arithmatic Average: 1037 #/in-width/face B Allowable Value: 934 #/in-width/face Standard Deviation: 46.7	Single Face
		2	1.900	0.543				
		3	1.932	0.542	3880	1004		Single Face
		4	1.932	0.543	4250	1100		Double Face
		5	1.929	0.542	3790	982		Single Face
		6	1.902	0.541	3940	1036		Double Face
		7	1.917	0.543	4060	1059		Single Face
		8	1.925	0.542	3930	1021		Single Face
		9	1.923	0.541	3690	959		Double Face
		10	1.922	0.542	3800	989		Single Face
		11	1.960	0.542	4310	1099		Double Face
		12	1.928	0.542	4060	1053		Double Face
		13	1.968	0.542	4270	1085		Double Face
		14	1.954	0.541	3650	934*		Clamp Area
30°	1/4	1	1.920	0.544	2300	599	Arithmatic Average: 589 #/in-width/face B Allowable Value: 501 #/in-width/face Standard Deviation: 4210	Double Face
		2	1.927	0.545	2160	560		Single Face
		3	1.903	0.542	2080	546		Clamp Area
		4	1.928	0.544	2180	565		Clamp Area
		5	1.926	0.544	2230	579		Double Face
		6	1.936	0.543	2120	548		Double Face
		7	1.994	0.544	2450	614		Double Face
		8	1.962	0.544	2220	566		Double Face
		9	1.971	0.543	2190	556		Double Face
		10	1.907	0.545	2510	658		Double Face
		11	1.879	0.544	2170	577		Double Face
		12	1.892	0.543	2150	568		Double Face
		13	1.934	0.544	2620	677		Double Face
		14	1.935	0.544	2470	638		Double Face

Load Angle	Core Cell	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
45°	1/4	1	1.955	0.544	1970	504	Arithmatic Average: 481 #/in-width/face B Allowable Value: 461 #/in-width/face Standard Deviation: 8.6	Double Face
		2	1.955	0.545				
		3	1.966	0.545	2100	534*		Bad Deformation
		4	1.919	0.542	1850	482		Double Face
		5	1.906	0.545	1820	477		Double Face
		6	1.913	0.545	2050	536*		Bad Deformation
		7	1.895	0.543	1830	483		Double Face
		8	1.896	0.545	1810	477		Double Face
		9	1.898	9.546	1920	506*		Bad Deformation
		10	1.922	0.545	1830	476		Double Face
		11	1.935	0.545	1870	483		Double Face
		12	1.934	0.545	1860	481		Double Face
		13	1.945	0.545	1840	473		Double Face
		14	1.957	0.545	1870	478		Double Face
60°	1/4	1	1.955	0.546	2230	570	Arithmatic Average: 544 #/in-width/face B Allowable Value: 506 #/in-width/face Standard Deviation: 17.9	Double Face
		2	1.973	0.547	2120	537		Double Face
		3	1.962	0.546	2270	578		Single Face
		4	1.918	0.546	2090	545		Double Face
		5	1.926	0.546	2050	532		Single Face
		6	1.931	0.547	2200	570		Double Face
		7	1.915	0.546	2000	522		Double Face
		8	1.932	0.546	2100	543		Double Face
		9	1.953	0.546	2100	538		Single Face
		10	1.940	0.546	2080	536		Single Face
		11	1.941	0.546	2030	523		Double Face
		12	1.930	0.546	2100	544		Double Face
		13	1.942	0.545	2140	551		Double Face
		14	1.955	0.546	2050	524		Double Face

Load Angle	Core Cell Size	Spec. No.	Width (inch)	Panel Thickness (inch)	Ultimate Load (#)	Ultimate Strength #/in-width/face	Statistical Allowables	Failure Mode
90°	1/4	1	1.915	0.545	4320	1128	Arithmatic Average: 982 #/in-width/face B Allowable Value: 846 #/in-width/face Standard Deviation: 59.9	Double Face
		2	1.950	0.545	3710	951		Double Face
		3	1.940	0.546	3960	1021		Single Face
		4	1.945	0.545	3950	1015		Single Face
		5	1.947	0.545	3460	889*		Clamp Area
		6	1.940	0.544	3730	961		Single Face
		7	1.919	0.543	3790	987		Double Face
		8	1.904	0.547	3550	932		Single Face
		9	1.884	0.547	3640	966		Single Face
		10	1.931	0.546	3200	829*		Clamp Area
		11	1.943	0.546	3860	993		Double Face
		12	1.936	0.547	3290	850*		Clamp Area
		13	1.942	0.548	3680	947		Double Face
		14	1.940	0.547	3500	902		Single Face

Section 4: Edgewise Compression Strain Gage Test Data

The following data has been reduced from readings taken directly off the BLH strain indicator. The Rosette Strain Gage Data Reduction Program as listed in Appendix 3, Section 3, was used to produce this reduced strain gage data output.

THE FOLLOWING SPECIMEN, EC 0 8 FRP, WAS TESTED ON 7/13/68

ORIENTATION 0 WARP NUMBER OF PLY = 3/FC WIDTH = 1.930 NO. OF FACES = 2.000

ULTIMATE STRESS = 1095. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	65 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	77.	-137557.	0.194	-565.	110.	-250.	110.	-565.	1.90 DEG. 0 TO 90
2	77.	-128251.	0.198	-606.	120.	-253.	120.	-606.	0.78 DEG. 0 TO 90
1	25.	-126374.	0.170	-205.	35.	-47.	40.	-210.	8.78 DEG. 0 TO -90
2	25.	-123365.	0.190	-210.	40.	-66.	41.	-211.	4.32 DEG. 0 TO -90
1	51.	-132855.	0.192	-390.	75.	-135.	76.	-391.	2.76 DEG. 0 TO -90
2	51.	-126374.	0.207	-410.	85.	-150.	85.	-410.	1.44 DEG. 0 TO -90
1	77.	-135165.	0.200	-575.	115.	-220.	115.	-575.	0.83 DEG. 0 TO -90
2	77.	-125355.	0.201	-620.	125.	-235.	125.	-620.	0.96 DEG. 0 TO -90
1	103.	-136891.	0.204	-757.	155.	-300.	155.	-757.	0.06 DEG. 0 TO -90
2	103.	-124104.	0.209	-835.	175.	-315.	175.	-835.	0.85 DEG. 0 TO -90
1	129.	-137072.	0.201	-945.	190.	-380.	190.	-945.	0.12 DEG. 0 TO 90
2	129.	-123365.	0.209	-1049.	220.	-400.	220.	-1050.	0.67 DEG. 0 TO -90
1	194.	-138786.	0.203	-1399.	285.	-565.	285.	-1400.	0.25 DEG. 0 TO 90
2	194.	-122975.	0.215	-1579.	340.	-590.	340.	-1580.	0.87 DEG. 0 TO -90
1	259.	-138539.	0.200	-1869.	375.	-760.	375.	-1870.	0.31 DEG. 0 TO 90
2	259.	-123565.	0.211	-2099.	465.	-770.	466.	-2101.	1.29 DEG. 0 TO -90

1	388.	-136351.	0.200	-2849.	570.	-1159.	570.	-2850.	0.33 DEG. 0 TO 90
2	388.	-122201.	0.215	-3179.	685.	-1139.	687.	-3182.	1.59 DEG. 0 TO -90
1	518.	-134930.	0.195	-3839.	750.	-1539.	750.	-3840.	0.06 DEG. 0 TO -90
2	518.	-120496.	0.212	-4299.	915.	-1519.	920.	-4305.	1.89 DEG. 0 TO -90
1	647.	-134930.	0.189	-4799.	910.	-1859.	910.	-4800.	0.55 DEG. 0 TO -90
2	647.	-118187.	0.208	-5479.	1139.	-1899.	1150.	-5490.	2.33 DEG. 0 TO -90
1	777.	-136112.	0.182	-5709.	1039.	-2179.	1043.	-5713.	1.31 DEG. 0 TO -90
2	777.	-114294.	0.202	-6799.	1379.	-2319.	1398.	-6818.	2.72 DEG. 0 TO -90
1	906.	-139069.	0.180	-6519.	1179.	-2579.	1181.	-6521.	0.66 DEG. 0 TO -90
2	906.	-139069.	0.180	0.	0.	0.	0.	0.	44.99 DEG. 90
1	1036.	-135815.	0.174	-7629.	1329.	-3049.	1330.	-7630.	0.51 DEG. 0 TO -90
2	1036.	-135815.	0.174	0.	0.	0.	0.	0.	44.99 DEG. 90

THE FOLLOWING SPECIMEN, EC 0 9 FRP, WAS TESTED ON 7/13/68

ORIENTATION 0 WARP   NUMBER OF PLY = 3/FC   WIDTH = 1.941   NO. OF FACES = 2.000

ULTIMATE STRESS = 1159. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	77.	-113646.	0.176	-680.	120.	-300.	120.	-680.	1.43 DEG. 0 TO 90
2	77.	-117090.	0.189	-660.	125.	0.	207.	-742.	17.13 DEG. 0 TO -90
1	25.	-107332.	0.187	-240.	45.	-115.	46.	-241.	3.30 DEG. 0 TO 90
2	25.	-117090.	0.181	-220.	40.	0.	68.	-248.	17.34 DEG. 0 TO -90
1	51.	-108462.	0.168	-475.	80.	-210.	80.	-475.	1.28 DEG. 0 TO 90
2	51.	-113230.	0.186	-455.	85.	0.	142.	-512.	17.20 DEG. 0 TO -90
1	77.	-114488.	0.185	-675.	125.	-285.	125.	-675.	0.71 DEG. 0 TO 90
2	77.	-115342.	0.194	-670.	130.	0.	212.	-752.	17.00 DEG. 0 TO -90
1	103.	-114488.	0.183	-900.	165.	-375.	165.	-900.	0.40 DEG. 0 TO 90
2	103.	-113855.	0.187	-905.	170.	0.	283.	-1018.	17.18 DEG. 0 TO -90
1	128.	-114999.	0.183	-1119.	205.	-460.	205.	-1120.	0.10 DEG. 0 TO 90
2	128.	-113981.	0.190	-1129.	215.	0.	255.	-1270.	17.11 DEG. 0 TO -90
1	193.	-114999.	0.184	-1679.	310.	-680.	310.	-1680.	0.14 DEG. 0 TO -90
2	193.	-113646.	0.191	-1699.	325.	0.	536.	-1911.	17.08 DEG. 0 TO -90
1	257.	-114999.	0.185	-2239.	415.	-890.	415.	-2240.	0.48 DEG. 0 TO -90
2	257.	-113981.	0.190	-2259.	430.	0.	711.	-2561.	17.11 DEG. 0 TO -90

1	386.	-112652.	0.182	-3429.	625.	-1349.	625.	-3430.	0.74 DEG.	0 TO -90
2	386.	-113646.	0.180	-3399.	640.	0.	1066.	-3826.	17.16 DEG.	0 TO -90
1	515.	-110557.	0.178	-4659.	830.	-1819.	831.	-4661.	0.99 DEG.	0 TO -90
2	515.	-112982.	0.183	-4559.	835.	0.	1415.	-5140.	17.31 DEG.	0 TO -90
1	643.	-109337.	0.173	-5889.	1019.	-2299.	1022.	-5892.	1.11 DEG.	0 TO -90
2	643.	-112194.	0.177	-5739.	1019.	0.	1762.	-6482.	17.46 DEG.	0 TO -90
1	772.	-106887.	0.168	-7229.	1219.	-2829.	1223.	-7233.	1.18 DEG.	0 TO -90
2	772.	-110085.	0.170	-7019.	1199.	0.	2125.	-7945.	17.64 DEG.	0 TO -90
1	901.	-104836.	0.161	-8599.	1389.	-3359.	1396.	-8606.	1.40 DEG.	0 TO -90
2	901.	-107846.	0.162	-8359.	1359.	0.	2489.	-9489.	17.88 DEG.	0 TO -90
1	1030.	-103142.	0.156	-9989.	1559.	-3919.	1567.	-9997.	1.46 DEG.	0 TO -90
2	1030.	-103142.	0.156	0.	0.	0.	0.	0.	44.99 DEG.	90
1	1159.	-102583.	0.150	-11299.	1699.	-4409.	1711.	-11311.	1.71 DEG.	0 TO -90
2	1159.	-102583.	0.150	0.	0.	0.	0.	0.	44.99 DEG.	90

6

THE FOLLOWING SPECIMEN. EC 30 4 FRP. WAS TESTED ON 7/13/68

ORIENTATION 30 WARP NUMBER OF PLY = 3/FC WIDTH = 1.943 NO. OF FACES = 2.000

ULTIMATE STRESS = 627. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	51.	-102583.	0.150	0.	405.	35.	465.	-60.	19.79 DEG. 0 TO 90
2	51.	-97107.	0.528	-530.	280.	00.	328.	-578.	13.42 DEG. 0 TO -90
1	25.	-75686.	0.558	-340.	190.	15.	204.	-354.	9.37 DEG. 0 TO -90
2	25.	-80416.	0.562	-320.	180.	10.	192.	-332.	8.87 DEG. 0 TO -90
1	51.	-73002.	0.524	-705.	370.	20.	401.	-736.	9.61 DEG. 0 TO -90
2	51.	-79793.	0.542	-645.	350.	20.	377.	-672.	9.30 DEG. 0 TO -90
1	77.	-71481.	0.527	-1079.	570.	25.	616.	-1126.	9.37 DEG. 0 TO -90
2	77.	-81263.	0.557	-950.	530.	40.	571.	-991.	9.33 DEG. 0 TO -90
1	102.	-70502.	0.544	-1459.	795.	40.	854.	-1519.	9.14 DEG. 0 TO -90
2	102.	-80416.	0.574	-1279.	735.	75.	793.	-1336.	9.51 DEG. 0 TO -90
1	128.	-68805.	0.556	-1869.	1039.	65.	1117.	-1947.	9.12 DEG. 0 TO -90
2	128.	-79424.	0.586	-1619.	950.	105.	1023.	-1693.	9.45 DEG. 0 TO -90
1	193.	-64119.	0.588	-3009.	1769.	170.	1897.	-3137.	9.14 DEG. 0 TO -90
2	193.	-73664.	0.622	-2619.	1629.	255.	1758.	-2748.	9.72 DEG. 0 TO -90
1	257.	-57958.	0.623	-4439.	2769.	350.	2959.	-4629.	9.09 DEG. 0 TO -90
2	257.	-66666.	0.663	-3859.	2559.	470.	2749.	-4049.	9.61 DEG. 0 TO -90

1	321.	-51139.	0.666	-6289.	4189.	645.	4457.	-6557.	8.96 DEG. 0 TO -90
2	321.	-59021.	0.713	-5449.	3589.	835.	4161.	-5721.	9.53 DEG. 0 TO -90
1	386.	-44266.	0.713	-8719.	6219.	1079.	6574.	-9074.	8.66 DEG. 0 TO -90
2	386.	-51398.	0.772	-7509.	5799.	1379.	6165.	-7875.	9.28 DEG. 0 TO -90
1	450.	-38821.	0.740	-11599.	8589.	1639.	9068.	-12078.	8.55 DEG. 0 TO -90
2	450.	-38821.	0.740	0.	0.	0.	0.	0.	44.99 DEG. 90
1	514.	-30274.	0.794	-16999.	15499.	2879.	14187.	-17687.	8.44 DEG. 0 TO -90
2	514.	-30274.	0.794	0.	0.	0.	0.	0.	44.99 DEG. 90
1	579.	-27183.	0.000	-21299.	0.	0.	4411.	-25711.	22.50 DEG. 0 TO -90
2	579.	-27183.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90
1	627.	-19607.	0.000	-31699.	0.	0.	6565.	-38265.	22.50 DEG. 0 TO -90
2	627.	-19607.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90

THE FOLLOWING SPECIMEN, EC 30 5 FRP, WAS TESTED ON 7/13/68

ORIENTATION 30 WARP   NUMBER OF PLY = 3/FC   WIDTH = 1.938   NO. OF FACES = 2.000

ULTIMATE STRESS = 619. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	51.	-77014.	0.388	-670.	260.	-965.	685.	-1095.	29.26 DEG. 0 TO 90
2	51.	-69729.	0.398	-740.	295.	-365.	314.	-759.	7.69 DEG. 0 TO 90
1	25.	-67894.	0.407	-380.	155.	-10.	173.	-398.	10.48 DEG. 0 TO -90
2	25.	-62926.	0.402	-410.	165.	-190.	172.	-417.	6.60 DEG. 0 TO 90
1	51.	-66580.	0.406	-775.	315.	0.	361.	-821.	11.44 DEG. 0 TO -90
2	51.	-70684.	0.431	-730.	315.	-345.	332.	-747.	7.37 DEG. 0 TO 90
1	77.	-67303.	0.421	-1149.	485.	0.	550.	-1215.	11.06 DEG. 0 TO -90
2	77.	-73713.	0.442	-1049.	465.	-515.	497.	-1082.	8.18 DEG. 0 TO 90
1	103.	-63312.	0.435	-1629.	710.	0.	797.	-1717.	10.73 DEG. 0 TO -90
2	103.	-70684.	0.465	-1459.	680.	-710.	726.	-1506.	8.32 DEG. 0 TO 90
1	128.	-62620.	0.446	-2059.	920.	0.	1025.	-2165.	10.46 DEG. 0 TO -90
2	126.	-70108.	0.478	-1839.	880.	-895.	941.	-1901.	8.48 DEG. 0 TO 90
1	193.	-58458.	0.477	-3309.	1579.	0.	1728.	-3458.	9.74 DEG. 0 TO -90
2	193.	-64499.	0.506	-2999.	1519.	-1459.	1631.	-3111.	8.83 DEG. 0 TO 90
1	257.	-54007.	0.496	-4769.	2369.	0.	2566.	-4966.	9.28 DEG. 0 TO -90
2	257.	-59309.	0.540	-4349.	2349.	-2139.	2538.	-4558.	9.39 DEG. 0 TO 90

1	322.	-48495.	0.518	-6649.	3449.	0.	3697.	-6897.	8.78 DEG. 0 TO -90
2	322.	-52860.	0.581	-6099.	3549.	-3019.	3855.	-6405.	9.94 DEG. 0 TO 90
1	386.	-60736.	0.548	-9499.	5209.	0.	5516.	-9806.	8.12 DEG. 0 TO -90
2	386.	-43976.	0.636	-8799.	5599.	-4349.	6107.	-9307.	10.45 DEG. 0 TO 90
1	451.	-43976.	0.636	0.	0.	0.	0.	0.	44.99 DEG. 90
2	451.	-14333.	0.250	-31499.	7899.	-5749.	8808.	-32408.	8.33 DEG. 0 TO -90
1	541.	-14333.	0.250	0.	0.	0.	0.	0.	44.99 DEG. 90
2	541.	-14447.	0.000	-37499.	0.	0.	7766.	-45266.	22.50 DEG. 0 TO -90
1	606.	-14447.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90
2	606.	-12764.	0.000	-47499.	0.	0.	9837.	-57337.	22.50 DEG. 0 TO -90
1	619.	-12764.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90
2	619.	-12383.	0.000	-49999.	0.	0.	10355.	-60355.	22.50 DEG. 0 TO -90

THE FOLLOWING SPECIMEN, EC 45 3 FRP, WAS TESTED ON 7/13/69

ORIENTATION 45 WARP NUMBER OF PLY = 3/FC WIDTH = 1.936 NO. OF FACES = 2.000

ULTIMATE STRESS = 586. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	51.	-64566.	0.481	-800.	385.	-100.	394.	-809.	5.14 DEG. 0 TO -90
2	51.	-54086.	0.476	-955.	455.	-140.	463.	-963.	4.43 DEG. 0 TO -90
1	25.	-56144.	0.478	-460.	220.	-100.	220.	-460.	1.68 DEG. 0 TO -90
2	25.	-75960.	0.500	-340.	170.	-70.	170.	-340.	1.68 DEG. 0 TO -90
1	51.	-54659.	0.497	-945.	470.	-170.	473.	-948.	2.72 DEG. 0 TO -90
2	51.	-67964.	0.526	-760.	400.	-145.	401.	-761.	1.72 DEG. 0 TO -90
1	77.	-53805.	0.527	-1439.	760.	-235.	764.	-1444.	2.72 DEG. 0 TO -90
2	77.	-64586.	0.541	-1199.	650.	-220.	651.	-1201.	1.70 DEG. 0 TO -90
1	103.	-49906.	0.565	-2069.	1169.	-295.	1177.	-2077.	2.73 DEG. 0 TO -90
2	103.	-56761.	0.576	-1819.	1049.	-305.	1052.	-1822.	1.59 DEG. 0 TO -90
1	129.	-50839.	0.574	-2539.	1459.	-355.	1468.	-2548.	2.64 DEG. 0 TO -90
2	129.	-56144.	0.578	-2299.	1329.	-370.	1333.	-2303.	1.81 DEG. 0 TO -90
1	193.	-45900.	0.623	-4219.	2629.	-485.	2643.	-4233.	2.58 DEG. 0 TO -90
2	193.	-48913.	0.616	-3959.	2439.	-570.	2445.	-3965.	1.69 DEG. 0 TO -90
1	258.	-40353.	0.679	-6399.	4349.	-605.	4366.	-6416.	2.23 DEG. 0 TO -90
2	258.	-41994.	0.658	-6149.	4049.	-760.	4058.	-6158.	1.62 DEG. 0 TO -90

1	322.	-33839.	0.728	-9539.	6949.	-690.	6972.	-9562.	2.09 DEG. 0 TO -90
2	322.	-35014.	0.699	-9219.	6449.	-945.	6462.	-9232.	1.60 DEG. 0 TO -90
1	387.	-27870.	0.784	-13899.	10899.	-750.	10922.	-13922.	1.73 DEG. 0 TO -90
2	387.	-27870.	0.784	0.	0.	0.	0.	0.	44.99 DEG. 90
1	451.	-19650.	0.000	-22999.	0.	0.	4763.	-27763.	22.50 DEG. 0 TO -90
2	451.	-19650.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90
1	516.	-14348.	0.000	-35999.	0.	0.	7455.	-43455.	22.50 DEG. 0 TO -90
2	516.	-14348.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90

THE FOLLOWING SPECIMEN, EC 45 4 FRP, WAS TESTED ON 7/13/68

ORIENTATION 45 HARP   NUMBER OF PLY = 3/FC   WIDTH = 1.934   NO. OF FACES = 2.000

ULTIMATE STRESS = 589. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	51.	-79548.	0.592	-650.	385.	-130.	385.	-650.	0.13 DEG. 0 TO -90
2	51.	-53032.	0.584	-975.	570.	-165.	570.	-975.	1.38 DEG. 0 TO -90
1	25.	-68941.	0.600	-375.	225.	-105.	226.	-376.	2.85 DEG. 0 TO 90
2	25.	-63056.	0.658	-410.	270.	-70.	270.	-410.	0.00 DEG. 0
1	51.	-65867.	0.585	-785.	460.	-185.	460.	-785.	1.03 DEG. 0 TO 90
2	51.	-63443.	0.619	-815.	505.	-145.	505.	-815.	0.43 DEG. 0 TO -90
1	77.	-64632.	0.600	-1199.	720.	-260.	720.	-1200.	0.59 DEG. 0 TO 90
2	77.	-63573.	0.622	-1219.	760.	-210.	760.	-1220.	0.57 DEG. 0 TO -90
1	103.	-61555.	0.625	-1679.	1049.	-340.	1050.	-1680.	0.52 DEG. 0 TO 90
2	103.	-60830.	0.635	-1699.	1079.	-280.	1080.	-1700.	0.61 DEG. 0 TO -90
1	129.	-59296.	0.637	-2179.	1389.	-415.	1390.	-2180.	0.32 DEG. 0 TO 90
2	129.	-58757.	0.649	-2199.	1429.	-350.	1430.	-2200.	0.55 DEG. 0 TO -90
1	193.	-52977.	0.685	-3659.	2509.	-600.	2510.	-3660.	0.23 DEG. 0 TO 90
2	193.	-51844.	0.695	-3739.	2599.	-540.	2600.	-3740.	0.27 DEG. 0 TO -90
1	258.	-49338.	0.736	-5239.	3859.	-730.	3860.	-5240.	0.25 DEG. 0 TO 90
2	258.	-47177.	0.733	-5479.	4019.	-720.	4020.	-5480.	0.06 DEG. 0 TO -90

1	323.	-42803.	0.810	-7549.	6119.	-845.	6121.	-7551.	0.54 DEG.	0 TO 90
2	323.	-39266.	0.792	-8229.	6439.	-915.	6440.	-8230.	0.07 DEG.	0 TO 90
1	387.	-35577.	0.887	-10899.	9669.	-950.	9675.	-10905.	0.93 DEG.	0 TO 90
2	387.	-35577.	0.887	0.	0.	0.	0.	0.	44.99 DEG.	90
1	452.	-28276.	0.942	-15999.	15399.	0.	15402.	-16002.	0.54 DEG.	0 TO -90
2	452.	-28276.	0.942	0.	0.	0.	0.	0.	44.99 DEG.	90
1	517.	-20765.	1.198	-24899.	27599.	-920.	27697.	-24997.	2.47 DEG.	0 TO 90
2	517.	-20765.	1.198	0.	0.	0.	0.	0.	44.99 DEG.	90
1	581.	-14578.	0.000	-39899.	0.	0.	8263.	-48163.	22.50 DEG.	0 TO -90
2	581.	-14578.	0.000	0.	0.	0.	0.	0.	44.99 DEG.	90
1	589.	-14034.	0.000	-41999.	0.	0.	8698.	-50698.	22.50 DEG.	0 TO -90
2	589.	-14034.	0.000	0.	0.	0.	0.	0.	44.99 DEG.	90

THE FOLLOWING SPECIMEN, EC 60 4 FRP, WAS TESTED ON 7/13/68

ORIENTATION 60 WARP NUMBER OF PLY = 3/FC WIDTH = 1.932 NO. OF FACES = 2.000

ULTIMATE STRESS = 672. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	51.	-60185.	0.412	-860.	355.	-395.	371.	-876.	6.60 DEG. 0 TO 90
2	51.	-79630.	0.500	-650.	325.	-330.	352.	-677.	9.48 DEG. 0 TO 90
1	25.	-63901.	0.456	-405.	185.	-155.	188.	-408.	4.33 DEG. 0 TO 90
2	25.	-63901.	0.469	-405.	190.	-180.	198.	-413.	6.84 DEG. 0 TO 90
1	51.	-68105.	0.427	-760.	325.	-285.	329.	-764.	3.54 DEG. 0 TO 90
2	51.	-68105.	0.467	-760.	355.	-325.	368.	-773.	6.19 DEG. 0 TO 90
1	77.	-68105.	0.425	-1139.	485.	-435.	492.	-1147.	3.76 DEG. 0 TO 90
2	77.	-68707.	0.482	-1129.	545.	-475.	564.	-1149.	6.14 DEG. 0 TO 90
1	103.	-66358.	0.435	-1559.	680.	-595.	690.	-1570.	3.93 DEG. 0 TO 90
2	103.	-67220.	0.496	-1539.	765.	-635.	791.	-1566.	6.06 DEG. 0 TO 90
1	129.	-65353.	0.444	-1979.	880.	-760.	895.	-1995.	4.17 DEG. 0 TO 90
2	129.	-67395.	0.513	-1919.	985.	-790.	1020.	-1955.	6.25 DEG. 0 TO 90
1	194.	-59907.	0.469	-3239.	1519.	-1279.	1556.	-3276.	5.00 DEG. 0 TO 90
2	194.	-63639.	0.550	-3049.	1679.	-1209.	1737.	-3107.	6.25 DEG. 0 TO 90
1	258.	-55536.	0.489	-4659.	2279.	-1879.	2347.	-4727.	5.42 DEG. 0 TO 90
2	258.	-60185.	0.586	-4299.	2519.	-1649.	2603.	-4383.	6.28 DEG. 0 TO 90

1	323.	-51926.	0.513	-6229.	3199.	-2599.	3323.	-6353.	6.47 DEG. 0 TO 90
2	323.	-56457.	0.617	-5729.	3539.	-2099.	3647.	-5837.	6.11 DEG. 0 TO 90
1	388.	-47168.	0.529	-8229.	4359.	-3499.	4551.	-8421.	6.98 DEG. 0 TO 90
2	388.	-47168.	0.529	0.	0.	0.	0.	0.	44.99 DEG. 90
1	452.	-38381.	0.555	-11799.	6549.	-5079.	6872.	-12122.	7.49 DEG. 0 TO 90
2	452.	-38381.	0.555	0.	0.	0.	0.	0.	44.99 DEG. 90
1	517.	-33393.	0.574	-15499.	8899.	-6699.	9364.	-15964.	7.78 DEG. 0 TO 90
2	517.	-33393.	0.574	0.	0.	0.	0.	0.	44.99 DEG. 90
1	582.	-28404.	0.104	-20499.	2149.	-8879.	2153.	-20503.	0.74 DEG. 0 TO -90
2	582.	-28404.	0.104	0.	0.	0.	0.	0.	44.99 DEG. 90

THE FOLLOWING SPECIMEN, EC 60 5 FRP, WAS TESTED ON 7/13/68

ORIENTATION 60 WARP   NUMBER OF PLY = 3/FC   WIDTH = 1.909   NO. OF FACES = 2.000

ULTIMATE STRESS = 595. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	52.	-56444.	0.430	-930.	400.	-305.	401.	-931.	1.72 DEG. 0 TO 90
2	52.	-60142.	0.412	-655.	270.	-40.	294.	-679.	9.12 DEG. 0 TO -90
1	26.	-69991.	0.426	-375.	160.	-115.	160.	-375.	0.80 DEG. 0 TO 90
2	26.	-68173.	0.402	-385.	155.	0.	178.	-408.	11.53 DEG. 0 TO -90
1	52.	-66029.	0.452	-795.	360.	-270.	362.	-797.	2.59 DEG. 0 TO 90
2	52.	-64016.	0.408	-820.	335.	0.	383.	-868.	11.38 DEG. 0 TO -90
1	78.	-65616.	0.462	-1199.	555.	-405.	558.	-1203.	2.68 DEG. 0 TO 90
2	78.	-64541.	0.418	-1219.	510.	0.	580.	-1290.	11.15 DEG. 0 TO -90
1	104.	-61757.	0.479	-1699.	815.	-585.	823.	-1708.	3.23 DEG. 0 TO 90
2	104.	-61395.	0.426	-1709.	730.	0.	824.	-1804.	10.94 DEG. 0 TO -90
1	131.	-60198.	0.495	-2179.	1079.	-750.	1092.	-2192.	3.49 DEG. 0 TO 90
2	131.	-59926.	0.438	-2189.	960.	0.	1075.	-2305.	10.66 DEG. 0 TO -90
1	196.	-56566.	0.528	-3479.	1839.	-1219.	1869.	-3509.	4.27 DEG. 0 TO 90
2	196.	-55607.	0.463	-3539.	1639.	0.	1608.	-3705.	10.07 DEG. 0 TO -90
1	262.	-51269.	0.566	-5119.	2899.	-1819.	2962.	-5182.	5.02 DEG. 0 TO 90
2	262.	-49151.	0.481	-5339.	2569.	0.	2805.	-5575.	9.64 DEG. 0 TO -90

1	328.	-46869.	0.608	-6999.	4259.	-2559.	4384.	-7124.	5.96 DEG. 0 TO 90
2	328.	-43861.	0.500	-7479.	3739.	0.	4043.	-7783.	9.21 DEG. 0 TO -90
1	393.	-41749.	0.664	-9429.	6269.	-3639.	6555.	-9695.	7.35 DEG. 0 TO 90
2	393.	-37495.	0.521	-10499.	5479.	0.	3864.	-10854.	8.71 DEG. 0 TO -90
1	459.	-34023.	0.725	-13499.	9709.	-5449.	10332.	-14042.	8.57 DEG. 0 TO 90
2	459.	-34023.	0.725	0.	0.	0.	0.	0.	44.99 DEG. 90
1	524.	-28246.	0.849	-19999.	16999.	-8559.	18312.	-21312.	10.48 DEG. 0 TO 90
2	524.	-28246.	0.849	0.	0.	0.	0.	0.	44.99 DEG. 90
1	595.	-20978.	0.000	-28399.	0.	0.	5881.	-34281.	22.50 DEG. 0 TO -90
2	595.	-20978.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90

THE FOLLOWING SPECIMEN, EC 90 4 FRP, WAS TESTED ON 7/13/68

ORIENTATION 90 WARP NUMBER OF PLY = 3/FC WIDTH = 1.940 NO. OF FACES = 2.000

ULTIMATE STRESS = 902. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	77.	-125722.	0.195	-615.	120.	-335.	130.	-625.	6.69 DEG. 0 TO 90
2	77.	-84502.	0.180	-915.	165.	-382.	165.	-915.	0.37 DEG. 0 TO 90
1	25.	-166278.	0.258	-155.	40.	-100.	48.	-163.	11.77 DEG. 0 TO 90
2	25.	-67824.	0.184	-380.	70.	-155.	70.	-380.	0.00 DEG. 0
1	51.	-133886.	0.220	-385.	85.	-218.	94.	-394.	8.06 DEG. 0 TO 90
2	51.	-79302.	0.184	-650.	120.	-265.	120.	-650.	0.00 DEG. 0
1	77.	-125722.	0.211	-615.	130.	-340.	142.	-627.	7.33 DEG. 0 TO 90
2	77.	-82254.	0.180	-940.	170.	-380.	170.	-940.	0.25 DEG. 0 TO -90
1	103.	-122729.	0.214	-840.	180.	-460.	196.	-856.	7.15 DEG. 0 TO 90
2	103.	-83139.	0.181	-1239.	225.	-500.	225.	-1240.	0.29 DEG. 0 TO -90
1	128.	-119320.	0.208	-1079.	225.	-580.	242.	-1097.	6.57 DEG. 0 TO 90
2	128.	-84780.	0.180	-1519.	275.	-615.	275.	-1520.	0.23 DEG. 0 TO -90
1	193.	-116445.	0.210	-1659.	350.	-895.	378.	-1688.	6.71 DEG. 0 TO 90
2	193.	-86294.	0.183	-2239.	410.	-920.	410.	-2240.	0.10 DEG. 0 TO 90
1	257.	-114040.	0.210	-2259.	475.	-1209.	511.	-2296.	6.53 DEG. 0 TO 90
2	257.	-87663.	0.180	-2939.	530.	-1219.	530.	-2940.	0.24 DEG. 0 TO 90

1	386.	-109517.	0.205	-3529.	725.	-1899.	782.	-3587.	6.58 DEG. 0 TO 90
2	386.	-88063.	0.182	-4389.	800.	-1819.	800.	-4390.	0.27 DEG. 0 TO 90
1	515.	-106500.	0.203	-4839.	995.	-2639.	1070.	-4925.	6.87 DEG. 0 TO 90
2	515.	-97218.	0.179	-5909.	1059.	-2469.	1060.	-5910.	0.36 DEG. 0 TO 90
1	644.	-104260.	0.203	-6179.	1259.	-3469.	1394.	-6314.	7.59 DEG. 0 TO 90
2	644.	-86255.	0.179	-7469.	1339.	-3179.	1341.	-7471.	0.74 DEG. 0 TO 90
1	773.	-102818.	0.200	-7519.	1509.	-4399.	1720.	-7730.	8.58 DEG. 0 TO 90
2	773.	-83679.	0.176	-9239.	1629.	-4039.	1635.	-9245.	1.23 DEG. 0 TO 90

THE FOLLOWING SPECIMEN, EC 10 5 FRP, WAS TESTED ON 7/13/68

ORIENTATION 90 WARP   NUMBER OF PLY = 3/FC   WIDTH = 1.930   NO. OF FACES = 2.000

ULTIMATE STRESS = 880. LBS/INCH WIDTH/FACE

GAGE NO.	STRESS (LBS/INCH WIDTH/FACE)	MODULUS SECANT (LBS/INCH WIDTH/FACE)	POISSONS RATIO	STRAINS MICRO IN/IN AXIAL	TRANSVERSE	45 DEGREES	PRINCIPAL STRAINS PHI AXIS	MINOR AXIS	PHI MEASURED CCWISE FROM AXIAL
1	77.	-130622.	0.151	-595.	90.	-130.	111.	-616.	9.84 DEG. 0 TO -90
2	77.	-90900.	0.175	-855.	150.	-210.	169.	-874.	7.91 DEG. 0 TO -90
1	25.	-136351.	0.105	-190.	20.	-85.	20.	-190.	0.00 DEG. 0
2	25.	-80958.	0.203	-320.	65.	-90.	65.	-323.	5.51 DEG. 0 TO -90
1	51.	-136351.	0.157	-380.	60.	-140.	60.	-380.	2.59 DEG. 0 TO -90
2	51.	-87819.	0.177	-590.	105.	-175.	111.	-596.	5.49 DEG. 0 TO -90
1	77.	-131729.	0.152	-590.	90.	-195.	94.	-594.	4.59 DEG. 0 TO -90
2	77.	-88318.	0.176	-880.	155.	-260.	165.	-890.	5.60 DEG. 0 TO -90
1	102.	-128729.	0.161	-805.	130.	-250.	138.	-813.	5.30 DEG. 0 TO -90
2	103.	-89333.	0.178	-1159.	205.	-345.	217.	-1172.	5.49 DEG. 0 TO -90
1	129.	-126993.	0.166	-1019.	170.	-320.	179.	-1029.	5.00 DEG. 0 TO -90
2	129.	-91220.	0.176	-1419.	250.	-415.	267.	-1437.	5.75 DEG. 0 TO -90
1	194.	-119938.	0.172	-1619.	280.	-435.	297.	-1637.	5.50 DEG. 0 TO -90
2	194.	-91651.	0.179	-2119.	380.	-625.	403.	-2143.	5.54 DEG. 0 TO -90
1	259.	-116697.	0.171	-2219.	380.	-650.	407.	-2247.	5.86 DEG. 0 TO -90
2	259.	-93865.	0.177	-2759.	490.	-820.	520.	-2790.	5.48 DEG. 0 TO -90

1	388.	-110085.	0.169	-3529.	600.	0.	1066.	-3995.	17.67 DEG. 0 TO -90
2	388.	-94780.	0.176	-4099.	725.	-1219.	769.	-4144.	5.48 DEG. 0 TO -90
1	518.	-107274.	0.170	-4829.	825.	-1339.	901.	-4906.	6.59 DEG. 0 TO -90
2	518.	-94896.	0.175	-5459.	960.	-1609.	1023.	-5523.	5.63 DEG. 0 TO -90
1	647.	-104126.	0.165	-6219.	1029.	-1679.	1143.	-6333.	7.08 DEG. 0 TO -90
2	647.	-92789.	0.173	-6979.	1209.	-2019.	1300.	-7070.	5.96 DEG. 0 TO -90
1	777.	-102533.	0.163	-7579.	1239.	-1999.	1392.	-7732.	7.42 DEG. 0 TO -90
2	777.	-89539.	0.168	-8679.	1459.	-2449.	1591.	-8811.	6.44 DEG. 0 TO -90
1	880.	-101595.	0.000	-8669.	0.	0.	1795.	-10465.	22.50 DEG. 0 TO -90
2	880.	-101595.	0.000	0.	0.	0.	0.	0.	44.99 DEG. 90

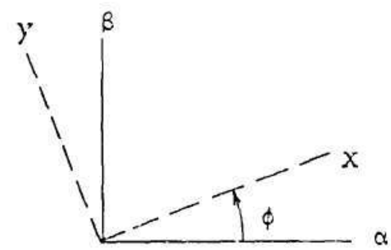
APPENDIX 3

COMPUTER PROGRAMS
(All Computer Programs Written in FORTRAN IV)

Section 1: MIL-HDBK-17 Orthotropic Transformation Equations

This computer program was adapted from an existing program developed at Lockheed-Georgia Company according to Reference 37. The program solves the following equations presented in MIL-HDBK-17, Reference 27.

x and y are the orthogonal axes at which the strength and modulus values are desired.



α and β are the orthogonal axes at which the strength and modulus values are known.

ϕ is the angle between α and x or β and y.

F_α, F_β, F_x are axial stresses in the direction indicated by the subscript.

$F_{\alpha\beta}$, F_{xy} are the shear stresses in the plane indicated by the subscripts.

E_α, E_β, E_x are the moduli in the direction indicated by the subscript.

$G_{\alpha\beta}$, G_{xy} are the shear moduli in the plane indicated by the subscripts.

$\nu_{\alpha\beta}$ is Poisson's ratio.

0, 90, 45 subscripts refer to actual orientations, in degrees, of the property related to the major laminate axis.

Axial Stress:
(Tension or Compression)

$$\frac{1}{F_x{}^2} = \frac{\mathrm{Cos}^4\phi}{F\alpha^2} + \frac{\mathrm{Sin}^4\phi}{F_\beta{}^2} + \left[\frac{1}{F\alpha\beta^2} - \frac{1}{F\alpha F\beta}\right] \mathrm{Sin}^2\phi\ \mathrm{Cos}^2\phi$$

Shear Stress:

$$\frac{1}{F_{xy}{}^2} = \frac{\mathrm{Cos}^2 2\phi}{F_{\alpha\beta}{}^2} + \left[\frac{1}{F\alpha^2} + \frac{1}{F\alpha F_\beta} + \frac{1}{F_\beta{}^2}\right] \mathrm{Sin}^2 2\phi$$

Modulus of Elasticity:
(Tension or Compression)

$$\frac{1}{E_x} = \frac{\mathrm{Cos}^4\phi}{E_\alpha} + \frac{\mathrm{Sin}^4\phi}{E_\beta} + \left[\frac{1}{G_{\alpha\beta}} - \frac{2\nu_{\alpha\beta}}{E_\alpha}\right] \mathrm{Sin}^2\phi \mathrm{Cos}^2\phi$$

Modulus of Rigidity:

$$\frac{1}{G_{xy}} = \frac{\mathrm{Cos}^2 2\phi}{G_{\alpha\beta}} + \left[\frac{1}{E_\alpha} + \frac{1}{E_\beta} + \frac{2\nu_{\alpha\beta}}{E_\alpha}\right] \mathrm{Sin}^2 2\phi$$

No shear tests were performed to obtain $F_{\alpha\beta}$ and $G_{\alpha\beta}$; however, axial tension (and compression) tests were performed at load angles of 0°, 90°, and 45°.

The shear values were calculated by substituting in the three known load angles and solving the above equations to obtain $F_{\alpha\beta}$ and $G_{\alpha\beta}$ as follows:

$$F_{\alpha\beta} = \sqrt{\frac{1}{\left(\frac{1}{F_0 F_{90}}\right) + \left(\frac{4}{F_{45}^2}\right) - \left(\frac{1}{F_0^2}\right) - \left(\frac{1}{F_{90}^2}\right)}}$$

$$G_{\alpha\beta} = \frac{1}{\left(\frac{2\nu_{\alpha\beta}-1}{E_0}\right) + \left(\frac{4}{E_{45}}\right) - \left(\frac{1}{E_{90}}\right)}$$

Such equations are solved by the computer program which then solves the first set of equations for F_x, E_x, F_{xy}, and G_{xy} for every 5° increment of ϕ. The input values required are F_0, F_{90}, F_{45}, E_0, E_{90}, E_{45}, $\nu_{0,\ 90}$ in tension and, if desired, in compression.

```
C       ORTHOTROPIC TRANSFORMATION EQUATIONS     MIL-HDBK-17
C
      DIMENSION TITLE(20),PHI(18),IDEG(18),EMOD(18),TEM5(18),SPHI(19),
     1MDEG(19),SRMOD(19),TM4(19),SSMAX(18),TERM6(18),SRMAX(19),
     2TRM3(19)
  100 READ(2,501)(TITLE(I),I=1,20)
      IF(TITLE(1))200,201,200
  200 WRITE(3,601)(TITLE(I),I=1,20)
      READ(2,502) TF00,TF90,TF45,CF00,CF90,CF45,XNU
      READ(2,503) TE00,TE90,TE45,CE00,CE90,CE45
C               TENSILE AND COMPRESSIVE STRENGTH VS. LOAD ANGLE
      NC=0
      IF(TF00)103,103,104
  104 IF(TF90)103,103,105
  105 IF(TF45)103,103,106
  106 WRITE(3,602)
      F00=TF00
      F90=TF90
      F45=TF45
      GO TO 107
  108 IF(CF00)109,109,110
  110 IF(CF90)109,109,111
  111 IF(CF45)109,109,112
  109 NC=NC+1
      GO TO 103
  112 F00=CF00
      F90=CF90
      F45=CF45
      NC=NC+1
      WRITE(3,603)
  107 TERM1=1.0/(F00**2.0)
      TERM2=1.0/(F90**2.0)
      TERM3=1.0/(F00*F90)
      TERM4=4.0/(F45**2.0)
      FSHR=SQRT(1.0/(TERM4-TERM1-TERM2+TERM3))
      TERM5=1.0/(FSHR**2.0)-TERM3
      DO 13 I=1,18
      IDEG(I)=5*I
      QI=I
      PHI(I)=1.5708*QI/18.0
      TERM6(I)=TERM1*COS(PHI(I))**4+TERM2*SIN(PHI(I))**4
     1+TERM5*((SIN(PHI(I)))**2)*((COS(PHI(I)))**2)
      IF(TERM6(I))117,117,13
   13 SSMAX(I)=SQRT(1.0/TERM6(I))
      WRITE(3,605)F00
      WRITE(3,606)
      DO 115 I=1,18
  115 WRITE(3,607)IDEG(I),SSMAX(I)
      IF(NC)108,108,117
  103 IF(NC)108,108,125
C                SHEAR STRESS VS. LOAD ANGLE
  117 CONTINUE
      WRITE(3,622)
      TA=1.0/(TF00**2.0)
      TB=1.0/(TF90**2.0)
      TC=1.0/(TF00*TF90)
      TD=TA+TB-TC
      TE=4.0/(TF45**2.0)
      TFSHR=SQRT(1.0/(TE-TD))
```

```
      CA=1.0/(CF00**2.0)
      CB=1.0/(CF90**2.0)
      CC=1.0/(CF00*CF90)
      CD=CA+CB-CC
      CE=4.0/(CF45**2.0)
      CFSHR=SQRT(1.0/(CE-CD))
      IF(TFSHR-CFSHR)118,118,119
  118 FSHR=TFSHR
      GO TO 120
  119 FSHR=CFSHR
  120 TRM1=1.0/(FSHR**2.0)
      DO 121 I=1,19
      MDEG(I)=-50+5*I
      SPHI(I)=-0.8727+1.5708*I/18.0
      IF(MDEG(I))122,122,123
  122 TRM2=1.0/(CF00**2.0)+1.0/(CF00*TF90)+1.0/(TF90**2.0)
      GO TO 124
  123 TRM2=1.0/(TF00**2.0)+1.0/(TF00*CF90)+1.0/(CF90**2.0)
  124 TRM3(I)=TRM1*COS(2.0*SPHI(I))**2+TRM2*SIN(2.0*SPHI(I))**2
      IF(TRM3(I))125,125,121
  121 SRMAX(I)=SQRT(1.0/TRM3(I))
      WRITE(3,608)TFSHR,CFSHR
      WRITE(3,609)FSHR
      WRITE(3,610)
      WRITE(3,611)(MDEG(I),SRMAX(I),I=1,19)
  125 CONTINUE
      NC=0
      IF(TE00)126,126,127
  127 IF(TE90)126,126,128
  128 IF(TE45)126,126,129
  129 E00=TE00
      E90=TE90
      E45=TE45
      WRITE(3,612)
      GO TO 130
  131 IF(CE00)132,132,133
  133 IF(CE90)132,132,134
  134 IF(CE45)132,132,135
  132 NC=NC+1
      GO TO 126
  135 E00=CE00
      E90=CE90
      E45=CE45
      NC=1
      WRITE(3,613)
  130 TEM1=1.0/E00
      TEM2=1.0/E90
      TEM3=1.0/E45
      TEM4=2*XNU*TEM1
      RSHR=4.0*TEM3+TEM4-TEM1-TEM2
      GSHR=1.0/RSHR
      DO 136 I=1,18
      IDEG(I)=5*I
      PI=I
      PHI(I)=1.5708*PI/18.0
```

```
      TEM5(I)=TEM1*(COS(PHI(I))**4)+TEM2*(SIN(PHI(I))**4)
     1+(RSHR-TEM4)*((SIN(PHI(I))**2)*(COS(PHI(I))**2))
      IF(TEM5(I))137,137,136
  136 EMOD(I)=1.0/TEM5(I)
      WRITE(3,616)E00
      WRITE(3,617)
      DO 138 I=1,18
  138 WRITE(3,618)IDEG(I),EMOD(I)
  137 IF(NC)131,131,139
  126 IF(NC)131,131,140
  139 CONTINUE
C                SHEAR MODULUS VS. LOAD ANGLE
      WRITE(3,623)
      TA1=1.0/TE00
      TB1=1.0/TE90
      TC1=4.0/TE45
      TD1=TC1-TA1-TB1+2.0*XNU*TA1
      TG1=1.0/TD1
      CA1=1.0/CE00
      CB1=1.0/CE90
      CC1=4.0/CE45
      CD1=CC1-CA1-CB1+2.0*XNU*CA1
      CG1=1.0/CD1
      IF(TG1-CG1)141,141,142
  141 G=TG1
      GO TO 143
  142 G=CG1
  143 TM1=1.0/G
      TM2=1.0/CE00+1.0/TE90+2.0*XNU/CE00
      TM3=1.0/TE00+1.0/CE90+2.0*XNU/TE00
      DO 144 I=1,19
      MDEG(I)=-50+5*I
      TI=I
      SPHI(I)=-0.8727+1.5708*TI/18.0
      IF(MDEG(I))145,145,146
  145 TM4(I)=TM1*COS(2.0*SPHI(I))**2+TM2*SIN(2.0*SPHI(I))**2
      GO TO 147
  146 TM4(I)=TM1*COS(2.0*SPHI(I))**2+TM3*SIN(2.0*SPHI(I))**2
  147 IF(TM4(I))100,100,144
  144 SRMOD(I)=1.0/TM4(I)
      WRITE(3,620)
      WRITE(3,621)(MDEG(I),SRMOD(I),I=1,19)
  140 GO TO 100
  501 FORMAT(20A4)
  601 FORMAT(1H1,20A4,//)
  502 FORMAT(7(1X,F6.2))
  503 FORMAT(6(1X,F4.2))
  602 FORMAT(1H0,//,15X,15H TENSILE STRESS)
  603 FORMAT(1H0,//,15X,19H COMPRESSIVE STRESS)
  605 FORMAT(1H0,31H MAX STRESS AT 0 LOAD ANGLE IS ,F7.2)
  606 FORMAT(1H0,9X,11H LOAD ANGLE,9X,11H MAX STRESS,/)
  607 FORMAT(1H,13X,I3,15X,F7.2)
  622 FORMAT(1H0,//,15X,13H SHEAR STRESS)
  608 FORMAT(1H0,15HTENSILE SHEAR =,F7.2,2X,19HCOMPRESSIVE SHEAR =,F7.2)
  609 FORMAT(1H0,5X,41H SHEAR USED AT ZERO DEGREE LOAD ANGLE IS ,F7.2)
  610 FORMAT(1H0,10X,11H LOAD ANGLE,9X,11H MAX STRESS,/)
  611 FORMAT(1H,14X,I3,13X,F7.2)
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612 FORMAT(1H0,//,15X,16H TENSILE MODULUS)
613 FORMAT(1H0,//,15X,20H COMPRESSIVE MODULUS)
616 FORMAT(1H0,3X,35H MODULUS AT 0 DEGREE LOAD ANGLE IS ,F7.2)
617 FORMAT(1H0,10X,11H LOAD ANGLE,12X,16H ELASTIC MODULUS,/)
618 FORMAT(1H ,14X,I2,22X,F7.2)
623 FORMAT(1H0,//,15X,14H SHEAR MODULUS)
620 FORMAT(1H0,10X,11H LOAD ANGLE,8X,14H SHEAR MODULUS,/)
621 FORMAT(1H ,14X,I3,15X,F7.4)
201 CALL EXIT
    END
```

Section 2: FPL 1810A Face Wrinkling Program

This program was written solely to solve the sandwich face wrinkling equation presented in the text in the Edgewise Compression Tests, Face Wrinkling Section of the Experimental Results and Evaluation discussion. The program was used for all load angle variations of the three types of sandwich construction investigated.

```
C     FACE WRINKLING ANALYSIS
C
      DIMENSION TITLE(20)
      READ (2,1000) BLANK
  200 READ (2,1000) (TITLE(I),I=1,20)
      IF(TITLE(1)-BLANK) 201,999,201
  201 WRITE (3,1004) (TITLE(I),I=1,20)
      PISQ=3.14159*3.14159
      READ (2,1001) TF,TC,XL,XKO,TT,ECZ
      SQTF=TF*TF
      DO 202 J=1,5
      READ (2,1002) EF,V12,V21,ANGLE
      XLAM=1.-(V12*V21)
      A=(PISQ*SQTF*EF)/(12.*XLAM*(XL**2))
      B=(24.*ECZ*XLAM*(XL**4))/(PISQ*PISQ*EF*TC*TF*SQTF)
      C=(2.*ECZ*XL*XKO)/(3.14159*TC*TT)
      SIGMA=A*((1.+B)/(1.+C))
      STRES=SIGMA*TF
  202 WRITE (3,1003) XL,ANGLE,SIGMA,STRES
      GO TO 200
 1000 FORMAT (20A4)
 1001 FORMAT (F5.3,1X,F5.3,1X,F6.4,1X,F5.3,1X,F5.0,1X,F7.0)
 1002 FORMAT (F8.0,1X,F5.3,1X,F5.3,1X,A4)
 1003 FORMAT (1H0,' CELL SIZE = ',F5.3,4X,'LOAD ANGLE = ',A4,' DEGREES',
     14X,'FACE WRINKLING STRESS = ',F8.0,' PSI = ',F6.0,
     2' LBS/IN WIDTH/FACE')
 1004 FORMAT (1H1,20A4///)

  999 CALL EXIT
      END
```

Section 3: Rosette Strain Gage Data Reduction Program

This program allows data input directly from the readings of any strain indicator. The strain readings may be input in any order as long as appropriate keying has been done to allow the computer to sort the strain gage arm readings and assign them to the proper rosette. If a reading is negative, the program calculates the compressive strain indicated. The program handles axial gages as single arm rosettes and biaxial gages as double arm rosettes. The program assumes a three arm rosette is a rectilinear gage with arms oriented 0°, 45° and 90° to the rosette axis.

For any set of strain readings, the corresponding load reading must be input. Depending upon the strain gage arms available, the program calculates the stress, secant modulus, Poisson's ratio, principal strains, and the angle (PHI) between the major principal strain and the rosette axis. The strain readings are also reduced from the raw test data and displayed.

The following equations are used, if needed:

Secant Modulus = $(\text{Stress}/\varepsilon_0) \times 10^{\varepsilon}$

Poisson's Ratio = $\left|\varepsilon_{90}/\varepsilon_0\right|$

Major Principal Strain

$$= \frac{\varepsilon_0 + \varepsilon_{90}}{2} + \frac{1}{2}\sqrt{(\varepsilon_0 - \varepsilon_{90})^2 + \left[2\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90})\right]^2}$$

Minor Principal Strain

$$= \frac{\varepsilon_0 + \varepsilon_{90}}{2} - \frac{1}{2}\sqrt{(\varepsilon_0 - \varepsilon_{90})^2 + \left[2\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90})\right]^2}$$

The angle PHI = $\frac{1}{2}\ \mathrm{Tan}\left[\frac{2\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90})}{\varepsilon_0 - \varepsilon_{90}}\right]$

where ε_0 = axial strain gage arm in micro inches/inch

ε_{90} = transverse strain gage arm in micro inches/inch

ε_{45} = 45° strain gage arm in micro inches/inch

are arms of the rosette.

```
C      DATA REDUCTION PROGRAM
C
C
C      THE PURPOSE OF THIS PROGRAM IS TO ACCEPT THE RAW DATA FROM STRAIN
C      GAGE TESTS AND PRESENT THE DATA SO THAT STRESS-STRAIN CURVES MAY
C      BE CONSTRUCTED
C
C      THE PROGRAM ACCEPTS DATA FROM UP TO 8 RECTANGULAR ROSETTES WITH
C      APPROPRIATE KEYING DONE TO ALLOW THE COMPUTER TO SORT THE GAGES
C      AND CYCLE AS MANY TIMES AS READINGS ARE INPUT.  ADDITIONAL TEST
C      SPECIMENS MAY ALSO BE STACKED AS DATA BLOCKS AND THE PROGRAM WILL
C      CYCLE THROUGH THEM
C
C
       COMMON IGAGE(8,3),ICK(24),L1(24),L2(24),L3(24),L4(24),
      1A1(24),A2(24),A3(24),A4(24),A5(24),ROSET(8,3),NA(8,3)
      2,SIGMA(40),EPSIL(40),A(101),X(40),Y(40),AXIS(5),KEY,XL,XH,YL,YH,
      3INCKT,NPTS
 1000 FORMAT(3A4,1X,2A4,1X,F5.3,1X,F5.3,1X,A4,1X,F6.0,1X,I2,1X,2A4,I3,
      11X,I1,/,4(1X,F7.0))
 1001 FORMAT(24(I2,1X))
 1002 FORMAT(1H1,'THE FOLLOWING SPECIMEN, ',3A4,', WAS TESTED ON ',2A4,
      1//' ORIENTATION  ',2A4,8X,'NUMBER OF PLY = ',A4,8X,'WIDTH = ',
      5F5.3,8X,'NO. OF FACES = ',F5.3,//' ULTIMATE STRESS = ',F8.0,
      2' LBS/INCH WIDTH/FACE'///' GAGE',1X,'STRESS',2X,
      3'MODULUS',3X,'POISSONS',10X,'STRAINS  MICRO IN/IN',12X,
      4'PRINCIPAL STRAINS',10X,'PHI MEASURED')
 1010 FORMAT(1H ,' NO.',9X,          'SECANT',4X,'RATIO',7X,'AXIAL',4X,
      1'TRANSVERSE',4X,'45 DEGREES',6X,'PHI AXIS',2X,'MINOR AXIS',6X,
      2'CCWISE FROM AXIAL',//)
 1003 FORMAT(F7.0,/8(I2,I4,I1,I1,I1,1X),/8(I2,I4,I1,I1,I1,1X),
      1/8(I2,I4,I1,I1,I1,1X))
 1004 FORMAT(/1X,I2,1X,F8.0,2X,F9.0,2X,F5.3,4X,F8.0,4X,F8.0,4X,F8.0,8X,
      1F8.0,4X,F8.0,3X)
 1005 FORMAT(1H+,97X,F6.2,' DEG. 0 TO 90')
 1006 FORMAT(1H+,97X,F6.2,' DEG. 0')
 1007 FORMAT(1H+,97X,F6.2,' DEG. 90')
 1008 FORMAT(1H+,97X,F6.2,' DEG. 0 TO -90')
 1009 FORMAT(A4)
 1011 FORMAT(1H0)
 1012 FORMAT(/1X,I2,1X,F8.0,2X,F9.0,2X,F5.3,4X,F8.0,4X,F8.0)
 1013 FORMAT(/1X,I2,1X,F8.0,34X,F8.0,4X,F8.0)
 1014 FORMAT(/1X,I2,1X,F8.0,2X,F9.0,11X,F8.0,16X,F8.0)
 1015 FORMAT(/1X,I2,1X,F8.0,2X,F9.0,11X,F8.0)
 1016 FORMAT(/1X,I2,1X,F8.0,34X,F8.0)
 1017 FORMAT(/1X,I2,1X,F8.0,46X,F8.0)
 1018 FORMAT(/1X,I2,1X,'THERE ARE NO GAGES FOR THIS NUMBER, THERE ',
      1'MUST BE SOME MISTAKE')
       READ (2,1009) BLANK
  901 READ (2,1000) SPE,CIM,EN,O1,O2,WIDTH,THICK,PLYNO,ULTLD,KEY,DA,TE,M
      2,LP,XL,XH,YL,YH
       KRD=KEY
       N=3*M
       IF (PLYNO-BLANK) 903,999,903
  903 READ (2,1001) ((IGAGE(I,J),J=1,3),I=1,M)
       DO 402 I=1,M
       DO 402 J=1,3
```

```
      NA(I,J)=0
      IF (25-IGAGE(I,J)) 401,401,402
  401 NA(I,J)=1
  402 CONTINUE
      AREA=WIDTH*THICK
      ULSTR=ULTLD/AREA
      WRITE (3,1002) SPE,CIM,EN,DA,TE,O1,O2,PLYNO,WIDTH,THICK,ULSTR
      WRITE (3,1010)
  902 READ (2,1003) XLOAD,(ICK(K),L1(K),L2(K),L3(K),L4(K),K=1,N)
      WRITE (3,1011)
      DO 500 I=1,M
      DO 500 J=1,3
      ROSET(I,J)=0.0
  500 CONTINUE
      DO 207 K=1,N
      A1(K)=L1(K)
      IF (A1(K)) 201,202,202
  201 A1(K)=(1000.+A1(K))*(-1.0)
  202 A2(K)=L2(K)
      A3(K)=L3(K)
      A4(K)=L4(K)
      A5(K)=(10.**A2(K))*(10.**A3(K))
      IF (A4(K)) 203,203,204
  203 A4(K)=1.0
  204 DO 206 I=1,M
      DO 206 J=1,3
      IF (ICK(K)-IGAGE(I,J)) 206,205,206
  205 ROSET(I,J)=A1(K)*A5(K)*A4(K)
      GO TO 207
  206 CONTINUE
  207 CONTINUE
      STRES=XLOAD/AREA
      SIGMA(KEY)=STRES
      DO 300 I=1,M
      AA=2.*ROSET(I,2)-(ROSET(I,1)+ROSET(I,3))
      BB=ROSET(I,1)-ROSET(I,3)
      IF(BB) 501,502,501
  502 TOPHI=1.5706
      GO TO 503
  501 TOPHI=ATAN(ABS(AA/BB))
  503 PHI=(TOPHI/2.)*57.2958
      TERM1=(ROSET(I,1)+ROSET(I,3))/2.
      TERM2=(.5)*(SQRT(BB**2+AA**2))
      EONE=TERM1+TERM2
      EPSIL(KEY)=EONE
      ETWO=TERM1-TERM2
      IF (ROSET(I,1)) 301,302,301
  301 XNU=ABS(ROSET(I,3)/ROSET(I,1))
      ESEC=(STRES/ROSET(I,1))*1000000.
  302 NC=NA(I,1)+NA(I,2)+NA(I,3)+1
      GO TO (314,303,308,313), NC
  303 IF (NA(I,2)) 304,305,304
  304 WRITE (3,1012) I,STRES,ESEC,XNU,ROSET(I,1),ROSET(I,3)
      GO TO 300
  305 IF (NA(I,3)) 307,306,307
  306 WRITE (3,1013) I,STRES,ROSET(I,3),ROSET(I,2)
      GO TO 300
```

```
307 WRITE (3,1014) I,STRES,ESEC,ROSET(I,1),ROSET(I,2)
    GO TO 300
308 IF (NA(I,1)) 310,309,310
309 WRITE (3,1015) I,STRES,ESEC,ROSET(I,1)
    GO TO 300
310 IF (NA(I,3)) 312,311,312
311 WRITE (3,1016) I,STRES,ROSET(I,3)
    GO TO 300
312 WRITE (3,1017) I,STRES,ROSET(I,2)
    GO TO 300
313 WRITE (3,1018) I
    GO TO 300
314 WRITE (3,1004) I,STRES,ESEC,XNU,ROSET(I,1),ROSET(I,3),ROSET(I,2),
   1EONE,ETWO
    IF(ROSET(I,2)-TERM1) 209,209,212
208 WRITE (3,1005) PHI
    GO TO 300
209 IF(ROSET(I,1)-ROSET(I,3)) 210,211,211
210 WRITE (3,1006) PHI
    GO TO 300
211 WRITE (3,1007) PHI
    GO TO 300
212 WRITE (3,1008) PHI
300 CONTINUE
    KEY=KEY-1
    IF(KEY)904,904,902
904 IF(LP)905,901,905
905 CALL SSCRV (EPSIL,SIGMA,KRD,XL,XH,YL,YH,1)
    GO TO 901
999 CALL EXIT
    END
```

Section 4: Standard Deviation Strength Data Reduction Program

This program adds up all the data points, input one value to a card; determines the number of data points to be averaged; calculates the standard deviation according to the equation presented in the Edgewise Compression Tests, Edgewise Compression Strength and Modulus Tests Section of the Experimental Results and Evaluation discussion; picks the appropriate k value from an input file; and calculates the reduced "B allowable" value, arithmatic average, maximum value, minimum value and 80 percent of arithmatic average value.

The k factors used are from Reference 36, and are as follows:

n	k	n	k	n	k	n	k	n	k
1	-	11	2.280	21	1.906	31	1.767	41	1.691
2	-	12	2.214	22	1.887	32	1.758	42	1.685
3	-	13	2.158	23	1.870	33	1.749	43	1.679
4	-	14	2.111	24	1.853	34	1.740	44	1.674
5	3.445	15	2.070	25	1.838	35	1.732	45	1.669
6	3.028	16	2.035	26	1.825	36	1.725	46	1.664
7	2.771	17	2.003	27	1.812	37	1.717	47	1.659
8	2.593	18	1.975	28	1.799	38	1.710	48	1.654
9	2.461	19	1.950	29	1.788	39	1.704	49	1.650
10	2.361	20	1.927	30	1.777	40	1.697	50	1.645

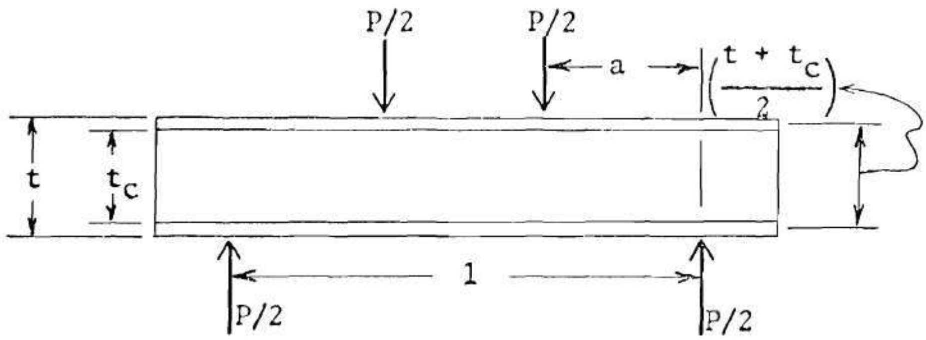
Where n is the number of test points.

```
C     STANDARD DEVIATION AND DESIGN ALLOWABLE STRENGTH VALUES
C
C       THIS PROGRAM IS DESIGNED TO TAKE A GROUP OF STRENGTH VALUES
C       AND EVALUATE  THE STANDARD DEVIATION . IT ALSO COMPUTES THE
C       B ALLOWABLE DESIGN VALUE BASED ON A 95 PERCENT CONFIDENCE
C       THAT 90 PERCENT OF ALL VALUES WILL FALL ABOVE THIS B
C       ALLOWABLE VALUE.
C
      DIMENSION DATA(100), TITLE(20), FACTK(50)
      READ(2,111)(FACTK(I),I=1,50)
  100 READ(2,101) (TITLE(I), I=1,20)
      IF(TITLE(1))200,201,200
  200 NC=1
  102 READ(2,103) DATA(NC)
      IF(DATA(NC))10,20,10
   10 NC=NC+1
      GO TO 102
   20 NC=NC-1
      DTOT=0.
      DMAX=-1.E30
      DMIN=1.E30
      DO 30 I=1,NC
      DMAX=AMAX2(DATA(I),DMAX)
      DMIN=AMIN2(DATA(I),DMIN)
   30 DTOT=DTOT+DATA(I)
      DAVG=DTOT/NC
      SQERR=0.
      DO 40 I=1,NC
   40 SQERR=(DAVG-DATA(I))**2+SQERR
      STDEV=SQRT(SQERR/(NC-1))
      BVAL=DAVG-FACTK(NC)*STDEV
      PCAVG=DAVG*(0.80)
  111 FORMAT(13(F5.3,1X))
  101 FORMAT(20A4)
  103 FORMAT(F10.2)
      WRITE(3,105)(TITLE(I), I=1,20)
  105 FORMAT(1H1, 20A4, //)
      WRITE(3,107)
  107 FORMAT(1H , 10X,'AVERAGE',5X,'MAXIMUM',5X,'MINIMUM',5X,'STANDARD',
     15X,'B',1X,'ALLOWABLE',5X,'NUMBER',5X,'80',1X,'PERCENT',/,
     212X,'VALUE',7X,'VALUE',7X,'VALUE',6X,'DEVIATION',7X,'VALUE',7X,
     3'OF',1X,'TESTS',4X,'OF AVERAGE')
      WRITE(3,109) DAVG, DMAX, DMIN, STDEV, BVAL, NC, PCAVG
  109 FORMAT(1H0,10X,2(F8.2,4X),F8.2,5X,F8.2,6X,F8.2, 7X,I4,6X,F8.2)
      GO TO 100
  201 CALL EXIT
      END
```

APPENDIX 4

SANDWICH FLEXURE ANALYSES AND COMPARISONS

(Following References 32 and 33)



Isotropic Bending Analysis

From various handbooks, such as Reference 38:

The center deflection, δ_{CL}, for an isotropic, homogeneous beam:

$$\delta_{CL} = \frac{(P/2)(a)}{6EI}\left[\frac{3}{4}\ 1^2 - a^2\right]$$

For the flexure tests, a = 2"

b = width = 3"

1 = 6"

$$\delta_{CL} = \left(\frac{23}{6}\right)\left(\frac{P}{EI}\right)$$

or

$$(EI)_{Experimental} = (3.8333)\left(\frac{P}{\delta_{CL}}\right)$$

For such sandwich structure where the faces are of equal thickness:

$I = 2\,Ad^2$ where A is the area of the face sheets and d is the distance from the center line of the sandwich to the center of the face sheet.

$$I = b(t - tc)\left[\frac{t + tc}{4}\right]^2$$

Now:

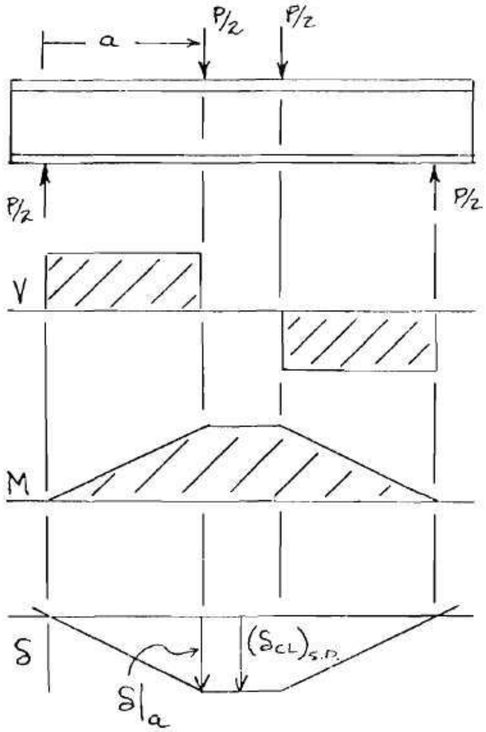
$$\left(E_{Effective}\right)_{Exp.} = \frac{(EI)_{Exp.}}{I}$$

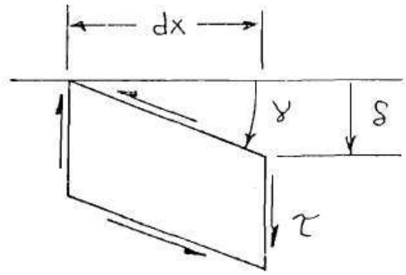
$$\left(E_{Effective}\right)_{Exp.} = \frac{(3.8333)\left(\frac{P}{\delta_{CL}}\right)}{(b)(t - tc)\left(\frac{t + tc}{4}\right)^2}$$

Part of the δ_{CL} in the above equation can be traced to shear deformation of the core which should be subtracted from the δ_{CL} obtained experimentally before calculating $\left(E_{Eff.}\right)_{Exp.}$

$$\left(\delta_{CL}\right)_{\substack{\text{Shear}\\ \text{Deformation}}} = \frac{(P)(a)}{\left(G_{xz}\right)_{core}(b)(t + t_c)}$$

can be derived from:





$$(\delta_{CL})_{S.D.} = \delta|_a$$

$$\tau = G\gamma \text{ or } \gamma = \frac{\tau}{G} = \frac{\delta}{dx} \quad \frac{\delta|_a}{a} = \frac{\tau|_a}{G} = \frac{V|_a}{AG}$$

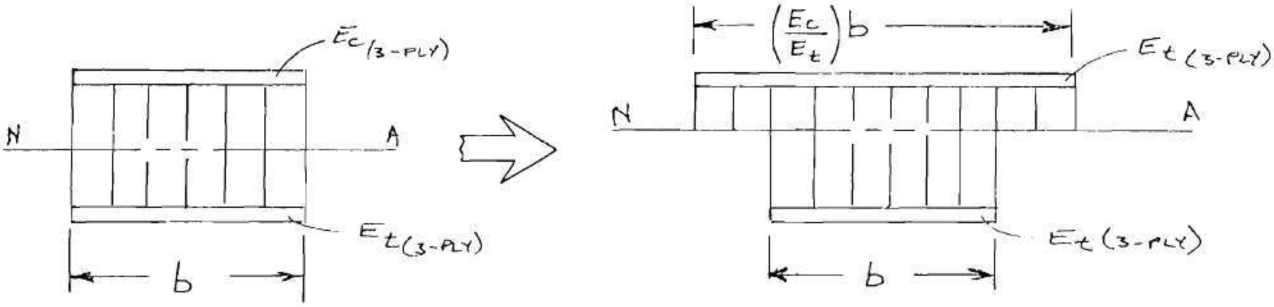
$$\delta|_a = \frac{(P/2)\,a}{b\left(\frac{t + t_c}{2}\right)\left(G_{\substack{core\\ xz}}\right)} \qquad \left(\delta_{CL}\right)_{\substack{\text{Shear}\\ \text{Deform.}}} = \frac{Pa}{\left(G_{xz}\right)_{core}(b)(t + t_c)}$$

Therefore, the calculated experimentally determined effective modulus of the three ply face sheet can be represented:

$$E_{\substack{\text{Eff.}\\\text{Exp.}}} = \frac{(3.8333)\left[\dfrac{P}{\delta_{CL} - \dfrac{Pa}{\left(\substack{Gxz\\core}\right)(b)(t + t_c)}}\right]}{(b)(t - t_c)\left(\dfrac{t + t_c}{4}\right)^2}$$

Effective Stiffness Analysis

Starting with the sandwich beam having face sheets with different moduli (since one face is in tension and the other in compression and $E_{tension} \neq E_{compression}$) an equivalent cross section is developed using an effective width calculated from the modulus ratio:

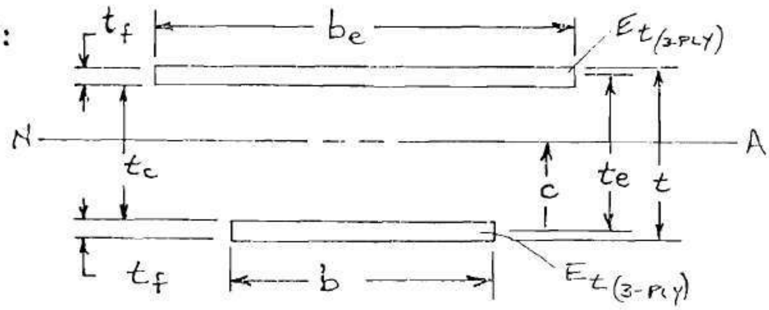


(CROSS-SECTION) (EQUIVALENT CROSS-SECTION)

The neutral axis shifts also.

I_{NA} is calculated:

$$\left[t_e = \left(\frac{t + t_c}{2}\right)\right]$$



$$b_e = \left(\frac{E_c}{E_t}\right) b$$

$$t_f = \left(\frac{t - t_c}{2}\right)$$

Find the centroid:

$$c = \frac{\Sigma \text{ Moment of Area}}{\Sigma \text{ Area}} = \frac{(b_e\ t_f)\ (t + t_c)/2}{t_f\ (b + b_c)}$$

$$c = \frac{\left(\frac{E_c}{E_t}\right)(b)\left(\frac{t - t_c}{2}\right)\left(\frac{t + t_c}{2}\right)}{(b)\left(\frac{t - t_c}{2}\right)\left(1 + \frac{E_c}{E_t}\right)} = \frac{\left(\frac{E_c}{E_t}\right)(t + t_c)}{2\left(1 + \frac{E_c}{E_t}\right)}$$

$$I_{NA} = A_1\ D_1{}^2 + A_2 D_2{}^2$$

$$= (b_e t_f)\left[\frac{t + t_c}{2} - c\right]^2 + (bt_f)c^2$$

$$I_{NA} = \left(\frac{t - t_c}{2}\right)(b)\left[\left(\frac{E_c}{E_t}\right)\left[\frac{t + t_c}{2} - c\right]^2 + c^2\right]$$

and $$(EI)_{Calc} = (E_{t_{3\ Ply}})\, I_{NA} = (E_{t_{3\ Ply}})(b)\left(\frac{t - t_c}{2}\right)\left[\frac{E_c}{E_t}\left[\frac{t + t_c}{2} - c\right]^2 + c^2\right]$$

Comparisons

The data from the sandwich flexure tests and the three ply laminate tests are used to calculate the effective modulus and effective stiffness and are then compared as follows:

Core Cell Size	1/8	3/16	1/4
P Load of Measurement (lb.)	400	400	800
δ_{CL} Measured center deflection (in.)	.0445	.0400	.0760
b width (in.)	2.995	2.955	2.940
t sandwich thickness (in.)	0.539	0.546	0.544
t_c core thickness (in.)	0.5	0.5	0.5
$G_{xz\,core}$ core shear modulus (psi)	40,000	90,000	115,000
E_t 3 ply tensile modulus (psi)	3.0×10^6	3.0×10^6	3.0×10^6
E_c 3 ply compressive modulus (psi)	3.35×10^6	3.35×10^6	3.35×10^6
$(E_{Eff})_{Exp.}$ (Using $\delta_{Bending}$) (psi)	5.11×10^6	4.44×10^6	4.87×10^6
$\delta_{Shear\ Deformation}$ (in.)	.00643	.00288	.00453
$\delta_{Bending}$ ($\delta_{CL} - \delta_{Shr.Def.}$) (in.)	.0381	.0371	.0715
$(EI)_{Experimental}$ (Using δ_{CL}) (lb.in.^{2})	34,500	38,300	40,400
$(EI_{Eff.})_{Experimental}$ (Using $\delta_{Bending}$) (lb.in^2)	40,300	41,300	42,900
$(EI)_{Calculated}$ for Sandwich (lb.in.^{2})	26,500	31,200	29,600

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